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This is to certify that the following thesis prepared under the direction of Professor A. N. Talbot, Head of the Department of Municipal and Sanitary Engineering, by

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entitled TEMPERATURE VARIATIONS IN CONCRETE

is hereby approved by me as fulfilling this part of the requirements for the Degree of Civil Engineer

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TEMPERATURE VARIATIONS IN CONCRETE.

INTRODUCTION.

During the past few years the use of concrete has increased very rapidly, so that now there is hardly a type of structure which has not been formed of this material. With this extension in the application of concrete a demand has been created for information relating to the design of such structures. One of the points which is often neglected in such designs is the determination of temperature stresses. The amount of the temperature stresses in any given structure is dependent upon the amount of the temperature changes therein. To determine these temperature changes is a somewhat difficult task; first, because there are so many dependent conditions to be taken into account; and second, because there is very little data given in engineering hand books which bears upon this subject. For this reason the writer undertook the experiments described in this thesis, with the intention of investigating the thermal conductivity of concrete and the amount of the temperature variations which occur in masses of that material.

PRINCIPLES OF TEMPERATURE VARIATION.

Before discussing the writer's experiments, it will perhaps be well to mention some of the principles involved and to define the terms used.

Definition of Terms.

THERMAL CONDUCTIVITY. The thermal conductivity of a material

is that quantity of heat which will flow, per unit of time, through unit area of a plate of unit thickness of the given material, when there is unit difference of temperature between the two faces.

TEMPERATURE GRADIENT. The flow of heat through a lamina of area A and thickness dr of a material having a thermal conductivity K and a difference in temperature between its two faces of dT, during the time t, will be equal to $KAt.\frac{dT}{dr}$. In this expression $\frac{dT}{dr}$ is the temperature gradient. That is, the temperature gradient is the rate of change in the temperature of a body per unit of distance, at a given point and for a given time.

SPECIFIC HEAT. The specific heat of a substance is the quantity of heat required to raise a unit mass one degree in temperature. The specific heat of water is taken as unity.

THERMAL CAPACITY. The thermal capacity of a material is the quantity of heat required to raise a unit volume one degree in temperature. The thermal capacity is equal to the specific heat of a substance multiplied by its density.

CALORIE. The calorie is the unit of heat which is used in the centimeter-gramme-second system. It is that quantity of heat which is required to raise one gramme of water one degree centigrade.

BRITISH THERMAL UNIT. (B.T.U.) The British thermal unit is the unit of heat used in the foot-pound-second system. It is that quantity of heat which is required to raise one pound of water one degree Fahrenheit. (1 B.T.U. = 252.1 calories.)

Discussion.

A warm body which is in contact with a cooler body will trans-

mit heat to it by conduction. That is the particles of the cool body which are in contact with the warm body become heated and they in turn heat other adjoining cooler particles. In this way a flow of heat is created which lowers the temperature of the warm body. The flow of heat by conduction is ordinarily considered to be proportional to the difference in temperature.

A warm body placed in a vacuum will receive or lose heat by radiation. In this case the heat is transferred through the ether as radiant energy. Every body is constantly emitting radiant energy and also absorbing radiant energy, but if it is warmer than the surrounding bodies it is emitting more energy than it absorbs and therefore its temperature falls. For given differences in temperature the rate of absorption is the same as the rate of emission. In general, dark surfaces have a higher rate of absorption and radiation than white surfaces. For differences of temperature which are not very great , the rate of radiation varies approximately as the difference in temperature.

If a warm body is surrounded by air the particles of air adjacent to the body are heated and are then removed by convection (air currents). The transfer of heat to the particles of air is by means of conduction, but since the heated particles are being constantly removed the temperature of the layer in contact with the air remains cooler than it otherwise would,thus causing a more rapid transfer of heat than would occur if the layer in contact with the air were stationary. For small differences of temperature the rate of cooling of a body in air, can be considered to be proportional to the difference in temperature between the body and the air, in accordance with Newton's law. For large differences of temperature the ratio becomes less.

(The limit within which Newton's law is correct is given in "Sewage Disposal in the United States" by Rafter and Baker, as 30 degrees F. difference in temperature.)

The properties just mentioned are those governing the quantity of heat which is transferred to or from the surface of an exposed body. To determine the change in temperature which will occur within the body, two other properties must be taken into account, viz. the rate at which the heat will flow through the material and the specific heat of the substance. The rate at which heat will flow through a material is expressed by the thermal conductivity. The flow of heat within a substance is essentially the same kind of a process as the conduction of the heat from the surface, except that in the first case heat is transferred from a molecule of one substance to a molecule of another substance. Since surface conduction involves two different materials the constants pertaining thereto are different from those for conduction within the material.

As above mentioned, the specific heat affects the rate at which the temperature in a material will change. One substance may be a better conductor of heat than another and still its temperature may change more slowly. Such a condition would occur if the thermal conductivity of the first substance were higher than that of the second while the specific heat of the second was higher than that of the first, the ratio of the specific heat of the second to the specific heat of the first being greater than the ratio of the thermal conductivity of the first to the thermal conductivity of the second.

The above are all of the properties of materials which govern the transfer of heat, but the determination of their combined of their combined effect upon the temperature of a given body may be complicated by the conditions in and surrounding that body. The presence of moisture in the body will affect its conductivity. The exposure of the body to the rays of the sun will create different conditions than those occuring in the shade. The mass of the body will affect the rise in temperature at a given point, since part of the heat which is transferred to that point will pass to the material beyond while the remainder will raise the temperature at that section. A retaining wall behind which there is a solid earth filling, will be subjected to a very much smaller range in temperature than a wall exposed on both sides. In the first case the heat will continually flow through the wall into the earth as long as the temperature of the air is greater than that of the wall, and when the temperature of the air is lower than that of the wall, the wall will receive heat from the earth behind it. In the latter case the temperature of the wall will be dependent, not only upon the properties of the wall, but also upon the thermal conductivity and the specific heat of the earth. These and other conditions which are encountered in the determinations for special cases, make the solution of such problems very difficult.

SCOPE OF EXPERIMENTS.

The time available for the experiments made by the writer was insufficient to permit of a complete investigation of all of the properties of concrete relating to the temperature variations

therein. Tests were made with the intention of securing data from which the temperature variations in a mass of concrete might perhaps be determined in an empirical manner. If the data should not prove to be sufficient to determine empirical constants, it would at least be possible to plot the information in the form of curves and from these curves the probable variations which would occur in other cases could be estimated. Such curves have been drawn for a part of the data obtained. Besides this, the thermal conductivity has been computed for one of the mixtures of concrete used and the specific heat for the same mixture has been determined. No attempt was made to compute the coefficients for surface conduction and radiation for the materials used, although the data may perhaps be sufficient to determine an approximate value for the rate of absorption and of cooling due to the combined effect of radiation and surface conduction.

DETAILS OF INVESTIGATION.

Six-inch Cubes.

The experiments made by the writer were begun by making four six-inch cubes of mortar compossed of 1 part(by weight) of Sandusky Portland cement to 3 parts of building sand. In each cube a hole was formed which would just allow a thermometer to be inserted, with its bulb near the center of the cube. After the cubes had been allowed to set indoors for a little over a month, they were placed out of doors and the temperature at the center of each cube and also the temperature of the air were observed at frequent intervals. The cubes were supported upon a shelf about fourteen feet above ground and on the south side of a projection from the west side of a wooden building. Each cube

was supported on blocks so that all six faces, with the exception of a small area on the lower face, were exposed. The cubes were in the shade during the forenoon, until about 11:50 A.M.,and were exposed to the sun during the afternoon.

Most of the observations for the cubes were taken with their surfaces exposed to the air. One cube (No.3) was covered on five sides with hair felt, Feb.16,1905, and the observations for this cube which were taken after that date are for the cube in that condition.

The temperatures observed in different cubes at the same time and under the same conditions, were practically the same.In plotting the results, the mean temperature for all of the cubes, for each set of observations, was plotted and also the air temperature. For the dates Feb.17th and Feb.18th, the temperatures observed in cube No.3, which then had only one face exposed, were plotted as well as the mean values for the temperatures in the other three cubes. The results of all of these observations are shown on page 59. The data obtained for the cubes is not given in tabular form since it is all plotted on the page referred to.

Concrete Cylinders.

After completing the preliminary tests above described, 3 large and 2 small concrete cylinders were made. The proportions of the ingredients used for the various specimens are given in Table I, page 10. The cement used was a mixture of five brands of portland cement. All of the cylinders were made in the Testing Materials Laboratory of the University of Illinois. After being allowed to set for at least a week, the specimens were re-

moved from the laboratory and were placed out of doors, on the north side of the east wing of the Engineering Building, in which position they were in the shade with the exception of a short time early in the morning. (A general view of the position of the specimens is shown on page 38 .)

The length of each of the large cylinders was 3 ft.6 in.and the diameter of each 1 ft. 5.4 in. At each end of each cylinder there were two one-inch layers of wood, between which was a one-inch layer of hair felt. The surface forming the circumference of each cylinder was left exposed in the condition in which it was removed from the mold.

The large cylinders were made in the manner and shape described, so that there would be very little heat flowing to or from the center of each cylinder through its ends, and so that the flow of heat at the points of observation could be assumed to take place radially.

When the concrete for the large cylinders was placed in the molds five 3/4-in. holes were formed, extending parallel to the axis, from one end half way to the other end. In each of these holes a wooden rod, with a diameter a little smaller than that of the hole was inserted. Near the lower end of each rod a groove was cut which was large enough to hold a thermometer. A thermometer was placed in each groove and a cover with a lock was attached to each cylinder. (The method of arranging the thermometers is shown in the diagram on page 36 and also in the photograph on page 39 .)

To read the thermometers mentioned, it was necessary to partially withdraw the wooden rods from the cylinders, but care

was used to take the readings as soon as possible so that there would be very little change before the observation was made. Readings of the thermometers, including one for the air temperature, were made at frequent intervals.

The length of each of the small cylinders was 2 ft. 8 in. And the diameter of each 0 ft. 8 in. At intervals along each cylinder, holes were formed in which thermometers could be inserted. These holes extended into the cylinders a little over one half of the diameter. The depth of the holes was made such that the bulbs of the thermometers would be very nearly at the axes of their respective cylinders. (The position and distance between thermometers is shown on page 37.)

All of the surface of each cylinder with the exception of one end, was covered with a one-inch layer of hair felt. The principal flow of heat was expected to pass through the exposed end. By means of the thermometers the temperatures at various distances from this exposed end could be determined.

Concrete Beam.

Besides the specimens above described, a piece of Beam No.8 of the tests described in Bulletin No.1 of the University of Illinois Experiment Station, was used in this investigation. The length of the portion of the beam used was about 6 ft. 4 in. One end was the section across which the original beam had been broken and was therefore, somewhat irregular. The width of the beam was 12 in. and the depth 14 1/2 in. At intervals along the beam holes were drilled, which extended from one 12-in. face to the axis. Thermometers were inserted in these holes and all of the surface of the beam, with the exception of the smooth end, was covered

with two one-inch layers of hair felt. (The arrangement and spacing of the thermometers is shown on pages 37 and 40.) This specimen also was placed north of the east wing of the Engineering Hall, and frequent readings of the thermometers were taken. Blocks were placed under the beam to support it a few inches above ground. A shelter was built over the beam to partially protect the hair felt from the weather, since the evaporation of moisture which had been absorbed by the felt, would have some effect upon the temperature of the concrete enclosed. The sides of the beam were not very well protected, but during the period covered by the observations, there were no hard rains, so it is thought that there are no material errors in the results from this source. (The arrangement of the beam and shelter is shown on page 38.)

Test Specimens.

The composition of the specimens above described and the dates at which they were made are given in the following table.

TABLE I.
Data on Specimens.

Kind of Specimen	No.	Proportion of Ingredients.			Date made	Remarks
		Cement.	Sand.	Broken Stone.		
Large Cylinders	1	1	3	6	Feb.14,'05.	
	2	1	2	4	Feb.18,'05	
	5	1	3	9	Mar.15,'05	
Small Cylinders	3	1	2	4	Feb.18,'05	
	4	1	3	6	Feb.18,'05	
Beam		1	3	6	Jan.18,'04	
Cubes	1	1	3	0	Dec.17,'04	Spoiled.
	2	1	3	0	Dec.17,'04	
	3	1	3	0	Dec.19,'04	
	4	1	3	0	Dec.23,'04	
	5	1	3	0	Dec.23,'04	

Determination of Specific Heat.

Five determinations of the specific heat of 1:3:6 concrete were made. A piece of concrete of the proportions named, was placed in a testing machine and crushed, so that most of the material would have passed a one-inch ring. (A great deal of the crushed material was in the form of dust.) This crushed concrete was placed in pans, weighed, and placed in a warming oven which was heated by steam and which was kept at a temperature of about 60 degrees centigrade. The material was left in the warming oven two days. At the end of that time, a series of readings of the temperature of the oven was taken, for at least an hour before removing the pans. From these readings the temperature of the concrete at the time it was removed, was estimated. A pail made of papier-mache, was partially filled with water and was weighed. A panful of crushed concrete was then removed from the oven and the concrete was emptied into the pail. The temperature of the water was noted both before and after the concrete had been added. The weight of the pail with both water and concrete was noted, for the purpose of determining the amount of moisture which had been removed from the concrete in drying. The weight of the empty pail and the empty pan were also observed.

After the crushed concrete had been added to the water the mixture was stirred to extract the heat from the concrete as soon as possible. The time required for thw water to reach its maximum temperature was about four or five minutes. The temperature of the water before the concrete was added, was about as much below the temperature of the room as its final temperature was above it. Furthermore, the temperature recorded for the water before

adding the concrete was taken about as long before the addition was made, as the time required for the water to reach its maximum temperature after the addition. These precautions were observed in order that the heat gained by absorption would about equal the heat lost.

Calibration of Thermometers.

To avoid large errors due to incorrect graduation, the thermometers used were calibrated. The method used for this work was as follows. A thermometer of a little better grade than those used in the tests, was taken as a standard. To compare the other thermometers with the standard, a number of them were bound together with it and were placed in a large beaker of water. The temperature of the water was then reduced to as low a point as desired by means of a freezing mixture. The readings of the thermometers were then taken in order, beginning and ending with the standard. The time between readings of successive thermometers was approximately uniform and the rate at which the water was changing temperature during readings was also nearly uniform, so the correct reading of the standard thermometer at the time of any particular observation, was obtained by adding to the first reading of that set the proportion of the difference between the first and last readings, that the number of the reading was of the total number for that set. After one set of readings had been taken in this manner, warm water was added to the water in the beaker to raise its temperature about one degree, and another set of readings was taken. Readings were taken in this manner for the entire range of temperature required for the tests. The difference between the reading of any thermometer for a given time

and the reading of the standard for that time, gave the correction required for the given thermometer at the temperature of the observation. These corrections were plotted for each thermometer and a curve was drawn through the points, thus making a diagram from which the correction for any temperature could be obtained.

The calibration curves for thermometers 7 to 19 is shown on page 60 . It is unfortunate that the standard used for the calibration of these thermometers was more in error than the thermometers themselves, but the diagram gives a correct comparison between the several thermometers.

COMPUTATION OF RESULTS.

Thermal Conductivity.

For the purpose of computing the thermal conductivity of 1:3:6 concrete, a portion of the data obtained for cylinder No.1 was plotted as shown on platesVII to XVII. The temperatures for each day's observations were first plotted, using the distances of the points of observation from the axis of the cylinder as abscissas, and the temperatures as ordinates. Through each set of points representing observations taken at the same time, curves were drawn, which show the fall of temperature from the surface to the axis of the cylinder. Lines were then drawn tangent to each of these curves at the points representing the temperatures 5cm., 10 cm., 15 cm., and 20 cm. distant from the axis. For each of these lines, the tangent of the angle between the line and the horizontal was measured. These values are the temperature gradients for the various points and times of observation. On the same plates on which the temperature curves described are drawn,

are plotted the values obtained for the temperature gradients, using the times of observation as abscissas and the temperature gradients as ordinates. These curves show the manner in which the rate of the flow of heat varied during the day.

After the curves had been drawn in the manner described, the differences in the ordinates for two consecutive temperature-distance curves were scaled for each centimeter of distance from the axis to a point 20 cm. from the axis. The differences thus obtained represent the rise in temperature which occured at the various distances from the axis, during the period between the two times of observation. Then, considering a disc one cm. in thickness, cut across the cylinder at its center, the volumes of annular rings of this disc, one cm. in width were computed for each centimeter of distance from the axis of the cylinder to a point 20 cm. therefrom. The product of the volume of any annular ring, by the rise in temperature for that ring, by the thermal capacity of concrete is equal to the quantity of heat which was added to the ring to produce the given rise in temperature. The total quantity of heat which was added to a portion of the disc included within a given radius, is equal to the sum of the products mentioned for all of the rings within the given radius. To express these relations in the form of equations,

let Q = the quantity of heat added to the portion of the disc having a radius r,

q = the quantity of heat added to one annular ring,

v = the volume of one annular ring in cc,

θ' = the initial temperature in degrees centigrade,

θ'' = the final temperature in degrees centigrade,

c = the thermal capacity of concrete in calories per cc.

Then $q = v.(\theta'' - \theta').c$ ——————————————————(1)

$Q = \Sigma_0^r q = \Sigma_0^r v.(\theta'' - \theta').c$ ——————————————(2)

The values of $v.(\theta'' - \theta')$ were computed for the curves given on pages 47 to 57 .

The total quantity of heat (Q) is also equal to the product of the thermal conductivity of concrete, by the area of the periphery of the portion of the disc included within the given radius, by the length of time during which the flow of heat continued, by the temperature gradient at the periphery considered; provided the temperature gradient has been constant or has varied uniformly during the given time. If the temperature gradient varied uniformly during the given time then the mean value should be used in the above product. To form an equation for the last expression, let K = the thermal conductivity of concrete,

A = the area in sq. cm. of the periphery of the portion of the disc included within a radius r,

Z = the temperature gradient in $\left(\frac{\text{degrees centigrade}}{\text{distance in cm.}}\right)$, at a distance r from the axis of the cylinder, during the time considered,

t = the period of time in seconds between the two sets of temperature observations.

Then $Q = K.A.Z.t = 2\pi r K Z t$ ——————————————————(3)

By equating (2) and (3),

$$\frac{K}{c} = \frac{\Sigma_0^r v(\theta'' - \theta')}{2\pi r Z t}$$ ——————————————————(4)

The values of A ($2\pi r$) were computed for the following values of r: 5 cm., 10 cm., 15 cm., and 20 cm., which are the same values of r for which the temperature gradient curves were drawn.

By equation (4), the values of $(\frac{K}{c})$ were computed for the various sets of observations, for the values of r stated above. In making these computations the temperature gradient curves were examined to see that the assumption that Z varied uniformly was not greatly in error for the portions of the curves used.

Specific Heat.

From the data obtained for the determination of the specific heat of concrete, the weight of dried concrete in each pan, the amount of moisture evaporated from each pan, and the weight of water used for each determination were computed. The specific heat of the concrete used was then computed by the following equations.

Let S' = the specific heat of dried concrete in calories per gr.

S = the specific heat of concrete before drying, in calories per gr.

c = the thermal capacity of undried concrete in calories per cc.

W' = the weight of dried concrete in any particular pan in grammes.

W = the weight of water in gr., used for the determination.

w = the weight of water evaporated in gr.

T'' = temperature of heated concrete in degrees centigrade.

T' = temperature of water in degrees centigrade, before adding concrete.

T = temperature of mixture in degrees centigrade.

D = density of concrete before heating = 2.25 for the concrete used.

Then $$S' = \frac{W(T - T')}{W'(T''-T)} \qquad (5)$$

$$S = \frac{W'S' + w}{W' + w} \qquad (6)$$

$$c = Ds \qquad (7)$$

The results for the determination of specific heat are given in Table III, page 23 .

RESULTS AND CONCLUSIONS.

The general way in which the temperature in concrete follows the temperature variations of the air is shown by the curves on pages 42 and 43 . The air temperature shown on these two pages was obtained from the Department of Soil Physics of the University of Illinois, and is copied from records made by a recording thermometer. The curves on pages 47 to 57 also show, more in detail, the variations in cylinder No. 1 for particular days.

In examining the curves shown on pages 43 and 44 , it should be remembered that although the beam was covered with the exception of one end, there was undoubtedly a considerable amount of heat conducted through the covering of hair felt, so that the curves representing the temperatures within the beam should show less variation than they do.

The distance from the exposed surface of the beam, which is subject to any considerable variation in temperature, is shown by the curves on page 44 . It will be seen that nearly all of the beam is at about the same temperature and that only that portion within a foot of the surface, is subject to any great daily variation. From these results it seems probable that for masses of

concrete of considerable size, especially if in contact with earth, the daily temperature variations can be neglected, and that the range of temperature changes throughout the year will be about equal to that of the mean daily temperature.

The time available was insufficient to permit the writer to plot or compute results from all of the data obtained, but the data for all of the specimens is given on pages 24 to 35, from which the difference in the results for the different mixtures of concrete used can be observed. The readings given for cylinder No.1 are corrected for errors in the calibration of the thermometers, but the readings for the other specimens are not so corrected. The calibration diagram for the thermometers used for cylinders No.2 and No.5 is given on page 60 and should be consulted, if computations are made from the data given.

Considering the results for both the cylinders and the beam, it seems probable that the variations in temperature which occur in small masses of concrete, such as walls of buildings, and also in material within six inches of the surface of large masses, will be only a few degrees less than the range in the air temperature.

Table II on page 21 gives the results of the values computed for $\frac{K}{C}$ for cylinder No.1. To obtain the value of the thermal conductivity (K), the coefficients given in the table must be multiplied by the thermal capacity of concrete, which was found to be 0.7745, as given in Table III. On page 41 are shown most of the values of $\frac{K}{C}$ plotted in such a manner as to show the relation which seems to exist between the thermal conductivity and the temperature gradient. In order that the values on the last named plate might be as accurate as possible, those val-

ues which were subject to large errors were not plotted. It was estimated that the error in thermometer readings would be 0.05 of one degree or 30 percent of 0.15. Therefore, those readings in which the difference in temperature was less than 0.15 were rejected in plotting Plate I. The estimated error in determining the temperature gradient (Z) was 0.005 or 30 per cent of 0.015. Hence, in making Plate I , readings were rejected in which the temperature gradient was less than 0.015. Errors in locating the temperature curves are indicated by lack of uniformity in the results for consecutive sets of observations, since the change in the position of a curve would increase the apparent amount of heat which was added during one period and decrease the apparent amount added during the other period. For this reason, consecutive results whose ratio was less than 2/3 , taking into account differences in temperature gradient, were rejected.

Table III on page 23 gives the results obtained for the specific heat and the thermal capacity of concrete.

In the appendix are given constants and other information pertaining to temperature variations, which the writer collected from the sources there stated. This information is given in order that the reader may obtain an idea of the values which might be expected for various substances. Considerable care is necessary in attempting to use information of this kind in computations, since there is a very great difference in the results obtained by different observers for the same material. To use such results it is necessary to inquire into their source and to determine by what method they were obtained.

For assistance in the preparation of this thesis, the writer

is very much indebted to Professor A. N. Talbot, Professor A.P.Carmen, Professor I.O.Baker, the Department of Soil Physics of the University of Illinois, and others.

TABLE II.

Computed Values of K/c for Cylinder No.1.

1:3:6 Concrete.

(To obtain K multiply values in table by 0.7745)

Date and Time of Observation	Distance of Point of Observation from Axis					
	5 centimeters			10 centimeters		
	Tem. θ	Temp.Grad. Z	K/c	Temp θ	Temp.Grad. Z	K/c
Mar.6,1905						
12:15-3:00P.	1.0	0.045	0.0043	1.3	0.065	0.00572
3:00-5:00 "	1.8	0.017	0.0128	1.9	0.037	0.01115
5:00-7:00 "	2.2	0.005	0.0141	2.3	0.022	0.00872
Mar.7,1905						
7:45-10:00A.	2.8	0.01	0.0031	2.8	0.005	0.0176
10:00-11:45	2.9	0.02	0.0040	3.0	0.025	0.0068
11:45-3:45P.	3.6	0.03	0.00715	3.8	0.055	0.0082
3:45- 4:55	4.3	0.04	0.00221	4.6	0.07	0.0035
4:55- 9:05	4.6	0.043	0.00132	4.8	0.05	0.00168
Mar.8,1905						
12:45-3:00P.	1.6	0.055	0.00515	1.9	0.07	0.00853
3:00 -5:00	2.4	0.050	0.00472	2.6	0.07	0.00573
Mar.9,1905						
11:00-11:50	0.8	0.065	0.0107	1.2	0.13	0.01043
11:50-12:50	1.6	0.075	0.00808	2.0	0.14	0.00913
12:50- 3:00	3.0	0.075	0.00605	3.5	0.135	0.00803
3:00 -4:00	4.2	0.065	0.00802	4.5	0.12	0.00825
Mar.10,1905						
2:15-5:30	2.9	0.026	0.00512	3.1	0.054	0.00518
Mar.15,1905						
10:00-11:30	1.3	0.03	0.017	1.5	0.12	0.0088
11:30-12:50	2.5	0.04	0.0171	2.8	0.13	0.0108
Mar.16,1905						
7:35-10:00	5.9	0.02	0.0225	6.2	0.08	0.012
Mar.17,1905						
7:55 -9:55	8.9	0.04	0.00432	9.2	0.065	0.00646
9:55-11:45	9.7	0.04	0.0130	10.1	0.10	0.00984
11:45-12:55	10.9	0.05	0.00745	11.4	0.125	0.00665
12:55- 3:10	12.5	0.055	0.01060	12.8	0.105	0.01018
3:10 -5:00	13.7	0.015	0.0185	14.0	0.065	0.00816
Mar.31,1905						
7:32-10:15	8.9	0.04	0.01032	9.1	0.07	0.0133
10:15-11:42	10.9	0.03	0.0379	11.1	0.07	0.0345
11:42- 3:30	13.5	0.02	0.0250	13.5	0.05	0.0207
3:30 -5:00	15.2	0.02	0.0207	15.3	0.045	0.0173

(Continued on page 22.)

TABLE II-Continued.
Computed Values of K/c for Cylinder No.1.
1:3:6 Concrete.

(To obtain K multiply values in table by 0.7745)

Date and Time of Observation	Distance from Axis to Point of Observation.					
	15 centimeters			20 centimeters		
	Temp. θ	Temp.Grad. Z	K/c	Temp. θ	Temp.Grad. Z	K/c
Mar.6,1905						
12:15 -3:00	1.7	0.12	0.0042	2.6	0.27	0.0019
3:00 -5:00	2.2	0.075	0.0082	2.8	0.21	0.0040
5:00 -7:00	2.5	0.045	0.00648	2.9	0.138	0.0257
Mar.7,1905						
7:45-10:00	2.9	0.005	0.0332	2.9	0.005	0.0477
10:00-11:45	2.2	0.043	0.0068	2.4	0.07	0.0088
11:45- 3:45	4.2	0.09	0.00783	4.6	0.185	0.0052
3:45- 4:55	4.9	0.06	0.00725	5.3	0.07	0.00625
4:55 -9:05	4.9	0.00	----	5.0	0.03	0.00227
Mar.8,1905						
12:45 -3:00	2.3	0.095	0.00995	2.8	0.15	0.0098
3:00 -5:00	2.9	0.100	0.0047	3.7	0.27	0.00174
Mar.9,1905						
11:00-11:50	2.0	0.245	0.00785	3.9	0.625	0.00385
11:50-12:50	2.9	0.24	0.00855	4.7	0.63	0.00470
12:50- 3:00	4.4	0.23	0.00705	6.1	0.58	0.00358
3:00- 4:00	5.4	0.185	0.00770	7.1	0.53	0.00341
Mar.10,1905						
2:15 -5:30	3.4	0.102	0.00414	4.2	0.34	0.00156
Mar.15,1905						
10:00-11:30	2.5	0.275	0.00615	4.4	0.54	0.00478
11:30-12:50	3.9	0.31	0.00706	6.3	0.83	0.00332
Mar.16,1905						
7:35-10:00	6.8	0.265	0.00682	9.6	0.765	0.0043
Mar.17,1905						
7:55- 9:55	9.6	0.125	0.00680	10.9	0.41	0.00374
9:55-11:45	10.8	0.24	0.00684	13.2	0.91	0.00296
11:45-12:55	12.4	0.28	0.00458	14.8	0.98	0.00166
12:55- 3:10	13.6	0.23	0.00618	15.5	0.72	0.00220
3:10- 5:00	14.4	0.165	0.00430	15.7	0.44	0.00151
Mar.31,1905						
7:32-10:15	9.7	0.28	0.00585	12.0	0.73	0.00412
10:15-11:42	11.7	0.315	0.00956	15.2	1.16	0.00273
11:42- 3:30	14.0	0.20	0.00794	16.5	1.11	0.00176
3:30- 5:00	15.6	0.135	0.00802	17.4	0.87	0.00125

TABLE III.

Results of Specific Heat Determinations.

1:3:6 Concrete.

No. of Sample	Specific Heat		Thermal Capacity
	Dried Concrete S'	Undried Concrete S	Undried Concrete c
1	0.2785	0.288	
2	0.282	0.291	
3	0.329	0.339	
4	0.3305	0.365	
5	0.256	0.266	
Mean	0.2952	0.3098	0.7745

DATA FOR CYLINDER NO.1.

Temperatures in Degrees Centigrade.

(Readings tabulated are Corrected for errors in calibration)

Date and Time of Observation.	Distance from center of cylinder 0 in.	2 in.	4 in.	6in.	7in.	Temperature of air
Mar.6,1905						
12:15 P.M.	0.55	0.7	1.0	1.6	1.8	3.0
3:00 "	1.45	1.5	1.8	2.2	2.3	3.4
5:00 "	2.15	2.2	2.2	2.4	2.5	3.3
7:00 "	2.35	2.4	2.6	2.6	2.7	3.3
Mar.7,1905						
7:45 A.M.	2.55	2.8	2.8	2.8	2.8	2.8
10:00 "	2.75	2.8	2.9	3.0	3.0	3.1
11:45 "	2.95	3.0	3.0	3.4	3.6	4.1
3:40 P.M.	4.15	4.2	4.5	4.8	5.0	5.7
4:55 "	4.25	4.4	4.7	5.0	5.1	5.2
9:05 "	4.55	4.8	4.7	4.8	4.8	4.6
Mar.8,1905						
7:40 A.M.	1.05	1.2	1.0	1.0	1.1	0.1
10:00 "	0.75	0.7	0.7	0.8	0.9	0.1
11:30 "	0.75	0.9	1.0	1.4	1.2	1.2
12:45 P.M.	0.95	1.1	1.2	1.7	1.8	1.9
3:00 "	1.85	1.9	2.3	2.8	3.1	4.1
5:15 "	2.45	2.8	3.0	3.1	3.2	4.7
8:30 "	2.55	3.2	3.8	2.3	1.7	0.1
Mar.9,1905						
7:45 A.M.	- 0.85	-0.9	-1.0	-1.2	-0.7	-0.9
10:00 "	-0.35	-0.4	0.0	0.8	2.0	4.1
11:00 "	0.35	0.2	0.9	1.8	2.5	5.1
11:50 "	1.05	1.1	1.6	2.5	3.1	5.8
12:50 P.M.	1.85	1.9	2.6	3.6	4.2	7.1
3:00 "	3.65	3.7	4.5	5.3	5.6	8.1
4:00 "	4.35	4.4	5.0	5.85	6.1	8.7
5:00 "	5.15	5.15	6.2	6.35	6.2	8.2
7:05 "	5.95	6.15	6.2	6.15	6.1	6.4
9:05 "	5.95	6.15	6.0	5.85	5.3	5.1
Mar.10,1905						
7:50 A.M.	1.15	1.4	1.3	1.1	1.2	-0.1
9:30 "	1.15	1.2	1.3	1.3	1.6	1.3
10:55 "	1.25	1.3	1.5	1.9	2.3	2.1
11:45 "	1.45	1.5	2.0	2.4	2.7	3.7
12:50 P.M.	1.85	1.9	2.2	2.6	2.8	4.1
2:15 "	2.15	2.3	2.6	2.8	3.3	5.1
5:30 "	3.15	3.4	3.5	3.8	3.5	4.5
Mar.13,1905						
7:35 A.M.	-1.85	-1.8	-2.0	-2.0	-2.0	---
10:00 "	-1.85	-1.8	-2.0	-1.6	-1.4	0.6
11:35 "	-1.65	-1.6	-1.3	-0.7	-0.1	0.9
12:50 P.M.	-1.15	-0.9	-0.8	0.4	0.9	2.0
3:05 "	0.15	0.2	0.7	1.4	1.4	2.3
4:35 "	0.75	1.1	1.3	2.3	1.6	2.6

DATA FOR CYLINDER NO.1.-Continued.

Date and Time of Observation	Distance from axis of cylinder. 0 in.	2 in.	4 in.	6in.	7 in.	Temperature of Air
Mar.14,1905						
7:45 A.M.	-0.15	0.0	0.0	-0.2	0.0	0.1
10:00 "	0.05	0.2	0.0	0.3	0.3	1.1
11:30 "	0.15	0.2	0.5	0.8	0.9	1.4
12:45 P.M.	0.35	0.4	0.7	1.0	1.3	2.1
3:00 "	1.15	1.2	1.0	1.3	1.3	0.1
4:45 "	0.95	1.0	1.0	0.8	0.5	-0.3
Mar.15,1905						
7:50 A.M.	-0.15	-0.1	0.0	0.2	0.4	1.1
10:00 "	0.65	0.8	0.8	1.8	2.8	4.1
11:30 "	1.65	1.8	2.1	3.1	4.1	7.6
12:50 P.M.	2.95	3.0	3.5	4.9	5.5	10.3
3:05 "	4.95	5.2	5.8	6.3	6.8	12.6
5:15 "	6.65	6.7	7.4	7.9	8.1	11.9
Mar.16,1905						
7:35 A.M.	4.65	5.2	5.1	5.15	6.1	8.6
10:00 "	6.65	6.6	7.0	8.2	10.1	15.1
11:30 "	8.15	8.2	9.1	10.0	11.1	17.5
12:45 P.M.	9.45	9.6	10.3	11.4	12.1	18.6
3:00 "	11.85	11.95	12.9	13.7	14.1	19.1
3:50 "	12.65	12.75	13.5	13.9	14.2	18.5
5:00 "	13.35	13.45	14.0	14.2	14.3	18.2
6:50 "	13.65	13.95	13.8	13.4	13.3	12.3
10:05 "	12.45	12.85	--	11.9	11.2	8.6
Mar.17,1905						
7:55 A.M.	8.55	8.85	---	8.65	10.0	10.1
9:55 "	8.95	9.15		10.1	10.8	14.8
11:45 "	10.2	10.2	10.5	11.9	12.6	18.5
12:55 P.M.	11.2	11.4	12.1	13.2	13.7	18.1
3:10 "	13.2	13.3	13.8	14.3	14.7	16.9
5:00 "	14.1	14.1	14.3	14.7	15.0	16.4
6:25 "	14.2	14.3		14.7	14.8	15.6
7:30 "	14.4	14.6		14.6	14.9	14.7
Mar.18,1905						
8:30 A.M.	12.9	13.1		12.9	13.3	14.3
Mar.20,1905						
7:50 A.M.	1.35	1.5		1.1	1.1	0.0
10:45 "	1.15	1.2		1.5	1.6	1.5
11:30 "	1.15	1.2		1.7	1.8	1.9
12:50 P.M.	1.35	1.5		2.1	2.3	2.5
3:08 "	2.05	2.2		2.7	2.7	3.1
4:15 "	2.35	2.4		2.8	3.0	3.2
5:15 "	2.45	2.5		2.8	3.1	3.1
Mar.21,1905						
7:45 A.M.	1.8	1.85		1.6	1.6	1.0
10:12 "	2.8	2.85		2.55	2.3	3.9
11:15 "	2.2	2.15		3.25	3.3	4.95
11:40 "	2.4	2.25		3.65	3.5	5.0
12:45 P.M.	3.1	2.95		3.85	4.0	4.9
3:15 "	4.0	4.0		4.75	4.5	5.5
4:05 "	4.2	4.15		4.85	4.6	6.2
5:45 "	4.4	4.65		4.85	5.8	5.0

DATA TOR CYLINDER NO.1-Continued.

Date and Time of Observation	Distance from axis of cylinder.					Temp.of air
	0 in.	2 in.	4 in.	6in.	7in.	
Mar.22,1905						
7:53 A.M.	3.2	3.35		3.65	4.8	5.8
10:10 "	4.4	4.35		5.85	7.8	9.9
11:40 "	5.7	5.75		7.3	8.8	12.2
12:40 "	6.75	6.65		8.1	8.8	14.8
3:10 P.M.	8.95	9.05		10.0	10.7	15.0
4:20 "	10.05	10.05		10.9	11.1	15.1
Mar.23,1905						
7:45 A.M.	9.05	9.1		9.0	9.2	11.6
9:50 "	10.25	10.2		11.9	13.8	18.0
10:57 "	11.55	11.6		13.15	13.8	17.3
11:55 "	12:45	12.5		14.0	14.9	18.4
2:30P.M.	14.3	14.3		15.1	15.1	16.5
Mar.24,1905						
7:40 A.M.	5.6	5.95		5.25	5.7	6.0
9:48 "	6.6	6.75		7.3	10.0	10.5
11:08 "	7.7	7.75		8.7	9.7	12.6
12:48 P.M.	8.85	8.95		9.8	10.5	13.8
2:50 "	10.15	10.15		11.2	11.8	14.6
4.25 "	11.25	11.3		12.05	12.2	14.7
Mar.25,1905						
7:55 A.M.	7.45	7.65		7.9	9.6	11.0
10:20 "	10.05	10.05		11.5	14.0	18.0
11.40 "	11.75	11.6		13.55	14.6	18.9
1:45 P.M.	13.85	13.9		15.0	15.4	19.1
3:45 "	15.3	15.3		15.8	15.6	15.0
4:50 "	15.4	15.4		15.1	15.0	14.1
Mar.27,1905			(New			
8:50 A.M.	8.95	9.15	thermom-	9.0	11.0	15.0
10:35 "	10.55	10.6	eter.)	11.2	14.0	19.0
11:42 "	12.5	12.1	11.9	11.9	15.0	19.5
12:40 P.M.	13.05	13.1	13.0	13.85	15.9	20.0
2:30 "	14.7	14.9	14.8	15.8	17.0	21.7
4:08 "	16.3	16.1	16.0	17.0	18.0	21.2
4:50 "	16.8	16.8	16.8	17.2	17.8	20.2
7:00 "	17.3	17.6	17.3	17.2	16.8	16.3
Mar.28,1905						
7:40 A.M.	14.2	14.1	14.2	14.2	14.5	17.0
10:10 "	16.1	16.3	16.0	16.3	18.7	22.3
12:40 P.M.	18.4	18.4	18.4	19.0	20.7	23.3
2:55 "	20.3	20.1	20.0	20.7	21.6	24.0
5:05 "	21.3	21.1	21.0	21.2	21.5	22.8
Mar.29,1905						
7:40 A.M.	14.3	14.3	14.0	14.0	13.8	13.0
10:15 "	14.1	14.1	14.0	14.0	14.1	12.1
11:32 "	14.1	14.0	13.7	13.8	13.5	10:0
Mar.30,1905						
7:30 A.M.	4.6	4.85	4.5	4.7	5.6	6.0
9:42 "	6.5	7.15	6.0	6.8	9.8	12.4
10:40 "	7.65	8.15	7.0	7.8	10.1	13.7
12:30 P.M.	9.15	9.15	8.9	9.6	10.8	15.0

DATA FOR CYLINDER NO.1-Continued.

Date and Time of Observation	Distance from axis of cylinder 0 in.	2 in.	4 in.	6 in.	7 in.	Temperature of air.
Mar.30,1905						
2:50 P.M.	10.55	10.85	10.7	11.2	11.8	15.2
5:10 "	11.75	11.95	11.8	12.0	12.1	14.7
6:32 "	12.15	12.15	12.0	12.2	12.0	12.7
Mar.31,1905						
10:15 A.M.	10.45	10.95	10.0	10.8	13.3	17.2
11:42 "	12.05	12.1	11.7	12.4	14.0	18.8
3:30 P.M.	14.60	14.7	14.7	15.2	16.0	20.7
5:00 "	15.50	15.5	15.5	15.9	16.4	20.2
6:28 "	16.1	16.1	16.0	16.0	16.0	16.8
8:03 "	16.1	15.9	15.8	15.7	14.8	13.1
Apr.4,1905						
7:35 A.M.	9.55	9.75	9.3	9.0	8.7	6.0
9:50 "	9.25	9.25	8.8	9.0	10.4	10.6
11:40 "	9.95	10.05	9.6	10.2	11.2	11.5
12.35 P.M.	10.25	10.25	10.0	10.9	11.8	15.0
3:10 "	11.25	11.3	11.0	11.8	12.1	13.1
Apr.6,1905						
7:30 A.M.	3.40	3.55	3.4	3.5	3.0	2.6
10:30 "	3.5	3.65	3.3	4.0	5.0	5.0
Apr.13,1905						
7:38 A.M.	6.7	6.95	6.4	6.1	10.0	7.7
9.28 "	8.25	8.75	7.5	7.5	12.6	12.0
10.45 "	9.75	10.15	9.0	10.0	12.5	15.0
11.45 "	10.45	10.75	10.0	10.5	12.9	16.1
12:40 P.M.	11.25	11.2	10.7	11.5	13.5	16.9
2:20 "	12.25	12.3	12.0	13.0	14.3	17.4
3:52 "	13.3	13.3	13.0	14.0	14.9	17.5
4:45 "	13.9	13.9	13.9	14.2	14.9	16.8
6:15 "	14.4	14.4	14.2	14.3	14.5	15.1
Apr.17,1905						
7:30 A.M.	1.4	1.65	1.3	1.7	5.0	5.5
8:40 "	2.6	2.95	2.0	3.0	7.7	8.5
9:45 "	4.2	4.95	3.6	4.0	8.7	8.2
11:05 "	6.2	6.35	5.3	5.9	8.9	9.0
12:45 P.M.	7.2	7.25	6.7	7.2	8.8	9.6
2:17 "	7.95	8.05	7.7	8.0	8.9	10.0
4:27 "	8.45	8.65	8.4	8.9	8.8	10.8
6:50 "	8.85	8.85	8.7	8.8	8.0	7.4

DATA FOR CYLINDER NO.2.

Temperature in Degrees Centigrade.
(Readings calibrated are not corrected for errors in calibration.)

Date and Time of Observation	Distance from center of cylinder					Temperature of air
	0 in.	2 in.	4 in.	6 in.	7 in.	
Mar.22,1905						
11:45 A.M.		5.6	5.8	4.8	10.1	12.1
12:55 P.M.	6.4	6.4	6.6	7.4	8.6	14.2
3:07 "	8.5	8.5	9.0	9.5	14.4	14.7
4:25 "	9.4	9.6	9.7	10.3	10.9	14.8
Mar.23,1905						
7:47 A.M.	9.0	9.0	9.1	9.0	9.3	11.6
9:52 "	10.0	10.0	10.5	11.2	12.5	17.5
11:00 "	11.0	11.1	11.6	12.4	13.0	17.0
11:57 "	12.0	12.0	12.4	13.4	14.3	18.1
2:32 P.M.	13.9	13.9	14.0	14.3	14.7	16.2
Mar.24,1905						
7:45 A.M.	5.8	5.9	6.0	5.3	5.1	5.4
9:50 "	6.0	6.3	6.6	6.7	6.8	9.8
11:10 "	7.0	7.0	8.5	7.5	8.0	11.3
12:50 P.M.	8.0	8.1	8.3	9.7	9.3	13.2
2:55 "	9.4	9.5	9.8	10.3	10.8	13.7
4:25 "	10.5	10.6	10.9	11.0	11.5	13.7
Mar.25,1905						
7:55 A.M.	7.5	7.6	7.8	7.8	7.8	--
10:25 "	9.0	9.1	9.7	10.5	11.0	(New Ther.)
11:45 "	10.4	10.6	11.0	12.3	13.0	18.0
1:47 P.M.	12.7	12.9	13.1	14.0	14.6	18.6
3:50 "	14.5	14.6	14.7	14.8	14.8	14.7
4:52 "	14.7	14.7	14.7	14.3	14.5	13.8
Mar.27,1905						
8:52 A.M.	8.9	8.9	9.0	9.2	10.1	14.1
10:40 "	10.0	10.0	10.1	11.7	13.0	18.4
11:45 "	11.1	11.1	11.3	12.8	14.0	19.0
12:40 P.M.	12.1	12.3	12.4	13.6	14.9	19.6
2:32 "	14.0	14.0	14.1	15.2	16.0	21.0
4:10 "	15.3	15.4	15.6	16.5	17.5	20.5
4:55 "	16.0	16.0	16.0	16.8	17.5	20.0
7:05 "	16.6	16.8	16.9	16.7	16.5	16.1
Mar.28,1905						
7:42 A.M.	14.0	14.0	14.0	14.0	14.5	16.0
10:12 "	15.1	15.1	15.6	16.4	17.5	22.0
12:43 P.M.	18.3	18.4	18.6	19.0	19.9	23.2
2:57 "	19.3	19.2	19.4	20.3	20.9	24.0
5:07 "	20.4	20.2	20.4	21.0	21.0	22.3
Mar.29,1905						
7:42 A.M.	14.0	14.0	14.0	14.0	13.9	12.9
10:17 "	14.0	13.9	14.0	14.0	14.0	12.1
11:35 "	13.8	13.7	13.6	13.5	13.4	9.9
Mar.30,1905						
7:32 A.M.	4.6	4.7	4.8	4.8	5.2	5.5
9:45 "	5.6	5.7	5.9	6.8	7.3	11.6
10:42 "	6.2	6.4	6.6	7.9	8.1	12.4
12:32 P.M.	8.0	7.9	8.0	9.0	9.7	14.0

DATA FOR CYLINDER NO.2-Continued.

Date and Time of Observation.	Distance from center of cylinder					Temperature of air.
	0 in.	2 in.	4 in.	6 in.	7 in.	
Mar.30,1905						
2:52 P.M.	9.8	9.7	8.0	9.0	9.7	14.0
5:10 "	11.0	11.0	10.2	11.4	11.8	14.1
6:35 "	11.5	11.5	11.6	11.0	11.7	12.2
Mar.31,1905						
7:35 A.M.	8.0	7.9	8.0	7.8	8.5	9.4
10:17 "	9.1	9.1	9.3	10.4	11.2	16.3
11:45 "	10.6	10.6	10.8	12.0	12.8	18.2
3:33 P.M.	13.7	13.8	13.9	14.6	15.2	20.0
5:03 "	14.6	14.6	14.8	15.6	15.8	19.6
9:08 "	15.0	15.0	15.1	14.8	14.7	13.3
Apr.4,1905						
7:35 A.M.	9.5	9.4	9.3	8.6	8.4	5.5
9:52 "	8.9	8.7	8.8	8.9	9.5	9.6
11:43 "	9.2	9.2	9.3	10.0	10.7	11.8
12:38 P.M.	9.8	9.7	9.8	10.7	11.2	12.6
3:10 "	11.0	10.8	10.8	11.4	11.8	12.6
Apr.13,1905						
7:40 A.M.	6.5	6.5	6.4	6.4	8.0	8.0
9:25 "	7.0	7.0	8.1	8.0	9.0	11.5
10:46 "	8.0	8.0	8.0	9.5	10.3	14.2
11:46 "	8.8	8.8	9.0	10.0	10.8	15.4
12:41 P.M.	9.4	9.6	9.6	10.9	11.8	16.5
2:21 "	11.0	10.8	11.0	12.2	13.0	16.8
3:53 "	12.0	12.0	12.0	13.1	13.8	17.1
4:47 "	12.6	12.6	12.65	13.6	14.1	16.4
6:17 "	13.2	13.1	13.2	14.0	14.0	15.0
Apr.17,1905						
7:35 A.M.	1.3	1.4	1.35	1.5	3.8	4.8
8:42 "	2.0	2.0	2.0	2.7	4.4	8.0
9:47 "	3.0	3.0	3.0	4.1	5.0	7.7
11:07 "	4.2	4.0	4.1	5.1	6.2	8.2
12:47 P.M.	5.3	5.5	5.5	6.3	7.1	9.3
2:18 "	6.4	6.5	6.6	7.1	8.0	10.1
4:28 "	7.5	7.6	7.7	8.0	8.3	9.8
6:56 "	7.9	8.0	8.1	8.0	7.5	6.8
Apr.18,1905						
7:42 A.M.	2.3	2.5	2.4	2.7	5.8	6.0
9:08 "	3.2	3.3	3.3	4.1	5.7	8.8

NOTE:- The numbers of the thermometers used in Cylinder No.2 are as follows.

Distance from axis.	No. of thermometer.
0 in.	8
2 "	9
4 "	10
6 "	11
7 "	12
Air	13

DATA FOR CYLINDER NO.5.

Temperature in Degrees Centigrade.
(Readings tabulated are not corrected for errors in calibration.)

Date and Time of Observation.	Distance from axis of cylinder. 0 in.	2 in.	4 in.	6 in.	7 in.	Temperature of air.
Mar.25,1905						
11:48 A.M.	11.0	11.1	12.2	12.5	13.2	18.8
1:52 P.M.	13.0	13.1	13.6	14.0	15.1	19.0
3:55 "	14.5	14.5	14.8	14.6	14.5	14.9
4:55 "	14.6	14.6	14.7	14.1	14.0	14.0
Mar.27,1905						
8:55 A.M.	8.8	9.0	9.0	9.2	9.4	14.8
10:40 "	10.1	10.4	10.7	11.7	11.5	18.8
11:45 "	11.4	11.7	12.0	13.0	12.8	19.5
12:45 P.M.	12.5	12.7	12.9	13.8	13.7	19.9
2:35 "	14.0	14.1	14.6	15.4	15.1	21.0
4:12 "	15.5	15.7	16.0	16.5	16.5	21.8
4:57 "	16.0	16.1	16.6	16.8	16.8	20.0
7:08 "	17.0	16.9	17.0	16.6	16.5	16.5
Mar.28,1905						
7:45 A.M.	14.0	14.0	14.1	14.0	14.2	16.5
10:15 "	15.6	15.7	16.1	16.8	16.8	23.3
12:45 P.M.	18.0	18.1	18.4	19.1	19.0	23.3
3:00 "	19.8	19.6	20.0	20.7	20.5	24.0
5:10 "	20.8	20.7	20.9	20.8	20.8	22.4
Mar.29,1905						
7:45 A.M.	14.0	14.0	13.8	13.6	13.8	13.0
10:20 "	13.9	13.9	13.8	13.8	13.7	12.2
11:35 "	13.8	13.8	13.2	13.0	13.0	10.0
Mar.30,1905						
7:35 A.M.	4.5		4.4	4.5	5.0	5.8
9:47 "	5.9		7.0	7.0	7.0	12.0
10:45 "	6.9	7.0	7.4	7.8	8.0	12.5
12:35 P.M.	8.4	8.3	8.7	9.3	9.6	14.7
2:55 "	10.0	10.0	10.3	10.7	11.0	15.5
5:12 "	11.0	11.0	11.3	11.4	11.8	14.4
6:35 "	11.6	11.5	11.7	11.6	11.9	13.6
Mar.31,1905						
7:37 A.M.	8.0	7.9	7.9	7.8	8.2	10.0
10:20 "	9.8	9.8	10.4	10.8	10.8	16.8
11:46 "	11.0	11.0	11.6	12.1	12.2	18.5
3:36 P.M.	13.9	14.0	14.3	14.9	15.0	20.6
5:06 "	14.8	14.8	15.1	15.7	15.7	19.7
9:10 "	15.2	15.1	15.2	14.8	15.0	13.8
Apr.4,1905						
7:40 A.M.	9.0	9.0	8.7	8.3	8.6	5.8
9:55 "	8.7	8.8	8.8	8.8	8.8	9.8
11:45 "	9.2	9.0	9.4	9.8	9.8	12.0
12:40 P.M.	9.8	9.6	10.0	10.3	10.3	12.6
3:12 "	10.8	10.7	10.9	11.1	11.2	12.9
Apr.13,1905						
7:45 A.M.	6.3	6.3	6.3		6.5	8.5
9:27 "	7.3		7.4	9.3	8.2	11.9
10:50 "	8.5		8.4	9.6	9.6	14.7

DATA FOR CYLINDER NO.5-Continued.

Date and Time of Observation.	Distance from axis of cylinder. 0 in.	2 in.	4 in.	6 in.	7 in.	Temperature of air.
Apr.13,1905						
11:47 A.M.	9.1		9.3	10.0		15.9
12:48 P.M.	9.9		10.2	10.7	11.1	17.0
2:23 "	11.2		11.7	12.0	12.7	17.3
3:55 "	12.2		12.6	12.8	13.4	17.4
4:48 "	13.0		13.1	13.6	13.8	16.7
6:18 "	13.6		13.7	13.9	14.0	15.0
Apr.17,1905						
7:37 A.M.	1.2		1.5	1.7	1.6	6.8
8:48 "	2.0		2.0	4.5	3.9	8.6
9:48 "	3.2		3.3	5.7?	4.6	8.4
11:09 "	4.6		4.8	6.0	6.0	9.0
12:48 P.M.	6.0		6.0	6.5	7.0	9.3
2:20 "	7.0		7.0	7.3	7.8	10.1
4:30 "	8.0		7.9	8.1	8.0	9.8
7:00 "	8.2		8.0	8.1	7.7	7.2
Apr.18,1905						
7:45 A.M.	2.5		2.6	2.7	2.7	10.5
9:10 "	3.2		3.7	6.0		8.8

NOTE:- The numbers of the thermometers used in Cylinder No.5 are as follows.

Distance from axis.	No. of thermometer.
0 in.	14
2 "	15
4 "	16
6 "	17
7 "	18
Air	19

DATA FOR CONCRETE BEAM.

Temperatures in Degrees Centigrade.

(Readings are not corrected for errors incalibration of thermometers.)

Date and Time of Observation	Distance from exposed end of beam.							Temp. of Air	Therm. in 2"felt
	6 in.	1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.		
Mar.16,1905									
11:35 A.M.	7.1	5.8	4.7	4.4	4.7	4.8	6.0	17.3	
12:50 P.M.	7.5	5.9	5.0	5.0	4.8	5.0	5.7	18.2	21.5
3:00 "	8.5	6.5	5.4	5.0	5.2	5.4	6.1	18.6	17.0
3:55 "	9.0	7.0	5.5	5.3	5.4	5.8	6.3	17.5	17.0
4:55 "	9.2	7.2	5.9	5.5	5.7	5.9	6.5	16.0	16.6
6:55 "	9.4	7.6	6.0	5.8	5.9	6.0	6.9	10.5	12.7
10:10 "	9.0	7.8	6.3	6.0	6.0	6.1	7.0	7.9	7.9
Mar.17,1905									
7:50 A.M.	7.7	7.5	6.8	6.3	6.3	6.6	6.9	9.8	9.4
9:55 "	8.1	7.8	7.0	6.5	6.7	6.8	7.1	14.2	13.0
11:45 "	9.0	7.9	7.2	6.8	7.0	7.0	7.6	18.0	15.4
12:55 P.M.	9.5	8.1	7.6	7.0	7.1	7.2	7.8	17.7	16.3
3:10 "	10.5	9.0	8.0	7.5	7.8	7.8	8.3	16.4	17.0
4:55 "	11.0	9.4	8.3	8.0	8.1	8.1	9.0	16.0	16.3
6:30 "	11.2	10.0	8.6	8.2	8.4	8.4	9.3	14.7	15.0
7:35 "	11.4	10.1	8.8	8.5	8.7	8.7	9.5	14.1	14.7
Mar.18,1905									
8:30 A.M.	11.5	11.0	10.2	9.8	10.0	10.0	10.3	13.6	13.0
Mar.20,1905									
7:50 A.M.	5.9	7.2	8.1	8.6	9.0	9.0	8.6	0.0	-0.6
10:40 "	5.3	6.5	7.6	8.0	8.4	8.4	8.0	1.6	1.0
11:25 "	5.2	6.3	7.4	8.0	8.3	8.4	8.0	1.7	1.2
12:45 P.M.	5.1	6.1	7.2	7.8	8.1	8.1	7.9	2.5	2.0
3:05 "	5.2	6.0	7.0	7.5	8.0	8.0	7.6	3.0	2.6
4:13 "	5.3	5.9	6.8	7.2	7.8	7.9	7.6	3.1	3.0
5:15 "	5.2	5.9	6.8	7.2	7.8	7.8	7.6	3.0	2.9
Mar.21,1905									
7:40 A.M.	4.1	4.8	5.3	6.0	6.3	6.3	6.1	1.1	0.8
10:10 "	4.0	4.6	5.1	5.75	6.0	6.1	6.0	3.5	2.0
11:10 "	4.1	4.4	5.05	5.8	6.0	6.05	6.0	5.0	2.15
11:40 "	4.2	4.5	5.0	5.7	6.0	6.0	6.0	4.8	3.6
12:45 P.M.	4.5	4.6	5.0	5.7	6.0	6.0	6.0	4.8	3.6
3:15 "	4.9	4.8	5.0	5.6	6.0	6.0	6.0	5.3	4.1
4:03 "	5.0	4.7	5.0	5.6	6.0	6.0	6.0	5.6	4.4
5:45 "	5.0	4.9	5.0	5.5	6.0	6.0	6.0	5.0	4.2
Mar.22,1905									
7:50 A.M.	4.7	4.8	5.0	5.2	5.7	5.8	5.8	5.5	3.6
10:07 "	5.0	5.0	5.1	5.2	5.7	5.8	5.9	9.0	7.0
11:35 "	5.8	5.2	5.2	5.3	5.8	5.9	6.0	12.3	9.0
12:50 P.M.	6.2	5.4	5.4	5.7	6.0	6.0	6.1	13.8	10.6
3:05 "	7.2	6.0	5.8	6.0	6.3	6.4	6.8	14.8	
4:40 "	8.0	6.4	6.0	6.2	6.4	6.7	7.0	15.0	12.1
Mar.23,1905									
7:42 A.M.	8.2	7.9	7.4	7.1	7.4	7.7	8.0	11.2	10.0
9:48 "	9.0	8.1	7.7	7.4	7.7	7.9	8.3	17.3	14.8
10:53 "	9.7	8.5	7.8	7.8	8.0	8.0	8.6	17.0	15.3

DATA FOR CONCRETE BEAM-Continued.

Date and Time of Observation	Distance from exposed end of beam.							Temp. of Air.	Therm. in 2" of Felt
	6 in.	1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.		
Mar.23,1905									
11:53 A.M	10.1	8.7	8.0	8.0	8.1	8.2	9.0	17.9	16.6
2:27 P.M	11.1	9.7	8.7	8.3	8.7	9.0	9.6	16.0	16.6
Mar.24,1905									
7:37 A.M.	8.2	9.0	9.0	8.9	8.9	9.0	9.0	6.0	4.4
9:45 "	8.6	8.7	8.9	8.9	8.9	9.0	9.0	10.4	8.2
11:05 "	8.9	8.8	8.9	8.9	9.0	9.0	9.0	12.2	9.5
12:45 P.M.	9.1	9.0	9.0	9.0	9.0	9.0	9.1	13.8	10.0
2:50 "	9.8	9.1	9.0	9.0	9.0	9.0	9.2	14.2	11.2
4.25 "	10.2	9.3	9.0	9.0	9.1	9.1	9.3	14.7	11.6
Mar.25,1905									
7:55 A.M.	8.7	8.9	8.8	8.7	8.8	8.9	8.9	11.0	8.6
10:15 "	9.5	9.0	8.9	8.8	8.9	8.9	9.0	18.1	13.6
11:40 "	10.1	9.2	9.0	9.0	9.0	9.0	9.2	18.3	15.0
1:40 P.M.	11.1	9.6	9.2	9.1	9.3	9.2	9.8	18.8	15.5
4:55 "	12.0	10.6	9.7	9.7	9.8	9.7	10.0	13.6	15.2
Mar.27,1905									
8:45 A.M.	9.9	10.0	9.9	9.8	9.9	9.9	9.8	14.2	12.0
10:35 "	10.7	10.1	10.0	10.0	10.0	9.9	10.0	18.5	15.0
11:38 "	11.1	10.2	10.1	10.0	10.0	10.0	10.1	18.9	16.3
12:38 P.M.	11.6	10.6	10.2	10.0	10.1	10.1	10.3	18.2	17.4
2:28 "	12.3	11.0	10.5	10.3	10.3	10.3	10.8	20.9	18.0
4:05 "	13.1	11.6	10.7	10.5	10.6	10.7	11.1	21.0	18.5
4:48 "	13.6	11.8	10.8	10.6	10.7	10.8	11.2	20.0	18.4
6:58 "	13.8	12.2	11.0	11.0	10.9	11.0	11.4	15.7	16.5
Mar.28,1905									
7:48 A.M.	12.3	13.8	12.0	11.7	11.8	11.8	12.0	16.4	16.9
10:15 "	14.2	13.2	12.3	12.0	12.0	12.2	12.7	22.5	20.3
12:48 P.M.	15.5	14.0	13.0	12.5	12.7	12.8	13.4	23.2	21.6
3:03 "	16.3	14.7	13.4	13.0	13.0	13.1	14.0	23.5	22.0
5:12 "	17.0	15.2	13.8	13.3	13.5	13.6	14.2	22.0	21.2
Mar.29,1905									
7:47 A.M.	14.4	14.6	14.0	13.7	13.8	13.8	14.0	12.7	13.0
10:22 "	14.3	14.6	14.1	14.7	13.8	13.8	14.0	12.2	13.2
11:38 "	14.1	14.4	14.0	13.8	13.8	13.8	13.9	9.7	10.8
Mar.30,1905									
7:40 A.M.	8.5	9.6	10.6	10.8	11.0	11.0	10.8	6.6	4.8
9:50 "	9.5	9.6	10.6	10.8	11.0	11.0	10.8	12.2	9.3
10:48 "	9.8	9.7	10.5	10.8	11.0	10.9	10.9	13.7	9.7
12:37 P.M.	10.2	10.0	10.5	10.8	11.0	11.0	11.0	14.4	11.0
3:00 "	10.8	10.3	10.6	11.0	11.1	11.0	11.1	15.2	12.0
5:15 "	11.2	10.6	10.7	11.0	11.1	11.1	11.2	14.0	12.6
6:42 "	11.3	10.9	10.7	10.9	11.2	11.3	11.4	11.8	12.0
Mar.31,1905									
7:40 A.M.	9.6	10.0	10.3	10.0	10.6	10.5	10.4		8.3
10:22 "	10.8	10.1	10.3	10.3	10.8	10.8	10.8	16.8	13.8
11:48 "	11.1	10.4	10.5	10.6	10.9	10.9	11.0	18.5	15.0
3:38 P.M.	12.6	11.4	11.0	11.0	11.2	11.2	11.6	20.4	16.8
5:08 "	13.0	11.7	11.1	11.1	11.2	11.3	11.8	19.3	17.0
9:15 "	13.0	12.2	11.5	11.4	11.7	11.8	12.0	12.9	13.8

DATA FOR CONCRETE BEAM--Continued.

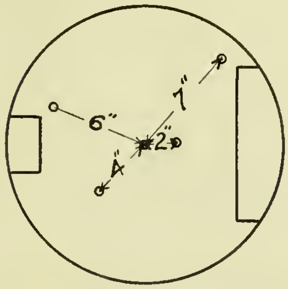
Date and Time of Observation	Distance from exposed end of beam.							Temp. of Air	Therm. in 2" of Felt.
	6 in.	1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.		
Apr.4,1905									
7:43 A.M.	12.1	13.8	14.1	13.9	14.0	14.0	13.8	6.0	5.2
9:58 "	11.8	13.0	13.7	13.5	13.7	13.7	13.4	9.8	8.0
11:48 "	12.0	12.7	13.3	13.2	13.4	13.4	13.1	11.8	8.9
12:43 P.M.	12.0	12.6	13.2	13.1	13.2	13.2	13.1	12.0	10.0
3:15 "	12.2	12.4	13.0	13.0	13.1	13.1	13.0	12.9	10.4
Apr.6,1905									
7:28 A.M.	6.5	7.5	8.4	8.8	9.0	9.0	8.9	2.4	2.4
10:28 "	6.2	7.1	8.0	8.5	8.8	8.8	8.7	5.3	3.2
Apr.13,1905									
7:48 "	8.0	8.0	8.5	8.5	8.7	8.75	8.75	7.2	6.8
9:30 "	8.5	8.1	8.5	8.6	8.8	8.8	8.8	12.0	9.5
10:52 "	9.0	8.4	8.5	8.65	8.8	8.85	9.0	14.7	11.5
11:50 "	9.3	8.6	8.6	8.7	8.9	8.9	9.0	15.5	12.0
12:45 P.M.	9.65	8.8	8.7	8.8	9.0	9.0	9.1	17.0	12.9
2:25 "	10.0	9.1	8.8	9.0	9.1	9.1	9.4	16.7	14.0
3:58 "	10.7	9.5	9.0	9.1	9.3	9.3	9.7	16.7	14.5
4:50 "	11.0	9.7	9.1	9.1	9.4	9.4	9.8	16.0	14.6
6:20 "	11.1	10.0	9.3	9.2	9.5	9.6	10.0	14.5	14.2
Apr.17,1905									
7:40 A.M.	3.2	3.5	3.8	4.0		4.3	4.4	4.2	2.4
8:47 "	3.6	3.4	3.8	4.0		4.3	4.4	6.8	5.5
9:52 "	4.1	3.6	3.9	4.0		4.3	4.5	8.7	5.6
11:12 "	4.8	3.9	4.0	4.1		4.5	4.7	9.0	6.2
12:50 P.M.	5.2	4.2	4.0	4.1		4.6	4.8	9.0	7.0
2:23 "	5.7	4.5	4.2	4.3		4.7	4.9	10.0	7.9
4:32 "	6.1	4.9	4.4	4.6		4.9	5.0	9.3	8.0
7:02 "	6.4	5.3	4.6	4.7		5.0	5.2	6.7	6.8
Apr.18,1905									
7:48 A.M.	4.3	4.3	4.4	4.3		4.7	4.7	5.7	4.0
9:18 "	5.0	4.4	4.5	4.4	5.0	4.7	4.8	8.3	5.5
12:40 P.M.	6.0	5.0	4.7	4.7	4.9	4.9	5.0	10.5	7.8

DATA FOR CYLINDERS NO.3 AND NO.4.
(Temperatures in Degrees Centigrade.)
(Readings are not corrected for errors in calibration of thermometers.)

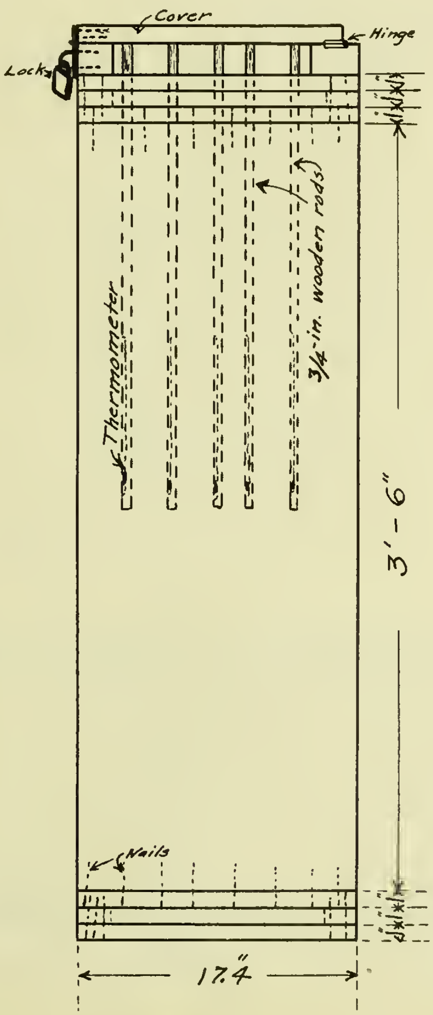
Date and Time of Observation	Tem. of Air	Cylinder No.3. Distance from exposed end 4 in.	8in.	14in.	20in.	26in.	Cylinder No.4. Distance from exposed end 4in.	8in.	14in.	20in.	26in.
Mar.25,1905											
2:00 P.M.	19.7	17.1	16.8	17.0	17.0	17.0	17.2	17.3	17.8	17.6	17.4
4:55 "	14.2	16.6	16.8	17.0	16.9	17.0	16.9	17.1	17.6	17.2	17.2
Mar.27,1905											
8:45 A.M.	14.2	9.7	9.8	10.1	10.2	10.3	9.8	10.0	10.8	10.7	10.8
10:30 "	18.6	11.3	10.7	10.8	10.7	10.9	10.8	10.7	11.1	11.0	11.1
11:35 "	19.1	12.0	11.0	11.0	11.0	11.3	11.8	11.1	11.6	11.4	11.6
12:35 P.M.	19.4	12.9	11.8	11.4	11.3	12.0	12.3	11.8	12.0	11.8	12.0
2:25 "	20.8	14.0	12.8	12.2	12.3	12.7	13.5	12.8	12.6	12.4	12.8
4:02 "	20.7	15.0	13.5	13.0	13.0	13.2	14.5	13.7	13.2	13.0	13.3
4:45 "	20.2	15.1	14.0	13.2	13.2	13.6	14.8	14.0	13.4	13.1	13.6
6:52 "	16.6	15.6	14.6	14.0	13.8	14.0	15.0	14.6		13.8	14.2
Mar.28,1905											
7:50 A.M.	17.0	14.6	14.3	14.6	14.4	14.5	14.3	14.4		14.5	14.5
10:20 "	22.3	16.2	15.2	15.5	15.2	15.4	15.6	15.2		15.1	15.4
12:50 P.M.	23.3	17.9	16.6	16.5	16.2	16.7	17.2	16.6		16.1	16.5
3:07 "	23.8	18.9	17.6	17.0	17.0	17.3	18.2	17.6		17.0	17.2
5:15 "	22.2	19.2	18.0	17.8	17.6	17.9	18.6	18.0		17.5	17.7
Mar.29,1905											
7:50 A.M.	13.4	14.2	14.7	15.4	15.3	15.6	14.3	14.9		15.7	15.5
10:25 "	13.0	14.3	14.4	15.0	15.0	15.3	14.3	14.7			15.3
Mar.30,1905											
7:45 A.M.	7.9	6.6	7.0	7.9	8.2	8.3	6.9	7.3			8.7
9:53 "	12.8	8.0	7.7	8.0	8.4	8.7	8.0	7.9			9.0
10:48 "	13.9	8.3	8.0	8.2	8.6	8.8	8.3	8.2			9.2
12:38 P.M.	15.2	9.4	8.7	8.7	9.0	9.4	9.4	8.9			9.6
3:00 "	15.6	10.7	9.8	9.6	9.7	10.0	10.4	9.8			10.2
5:15 "	14.6	11.2	10.5	10.0	10.1	10.4	11.0	10.5			10.7
6:45 "	12.7	11.5	10.8	10.4	10.4	10.8	11.1	10.8			11.0
Mar.31,1905											
7:45 A.M.	11.0	8.8	9.0	9.1	9.1	9.3	8.7	8.9			9.5
10:25 "	16.8	10.5	9.8	9.8	9.8	9.9	10.0	9.8			10.2
11:50 "	14.9	11.6	10.6	10.2	10.3	10.8	11.1	10.5			10.8
3:40 P.M.	19.7	13.7	12.5	12.0	11.9	12.2	13.0	12.3			12.0
5:10 "	18.7	14.0	13.0	12.5	12.3	12.7	13.5	12.8			12.7
9:17 "	13.5	13.9	13.5	12.9	13.0	13.1	13.4	13.2			12.9
Apr.4,1905											
7:45 A.M.	6.8	9.5	11.0	12.0	12.2	12.2	9.8	11.3			12.5
10:00 "	10.7	9.7	10.3	11.2	11.6	11.7	10.0	10.8			12.0
11:50 "	12.0	10.2	10.3	11.0	11.3	11.6	10.3	10.8			12.0
12:45 P.M.	12.6	10.5	10.5	11.0	11.2	11.6	10.6	10.8			12.0
3:15 "	13.2	11.0	10.8	11.0	11.1	11.5	11.0	11.0			11.7
Apr.13,1905											
7:50 A.M.		7.0	7.0	7.2	7.4	7.6	7.0	7.0			7.6
9:32 "		7.7	7.5	7.5	7.6	7.8	7.5	7.4			7.9
10:54 "		8.6	8.0	8.0	8.0	8.3	8.2	7.9			8.3
12:46 P.M.		9.8	9.0	8.6	8.7	9.0	9.4	8.7			9.0
2:25 "		10.7	9.8	9.3	9.3	9.6	10.3	9.65			9.7
4:00 "		11.4	10.3	9.7	9.7	9.9	11.0	10.2			9.9
4:52 "		11.7	10.6	10.0	10.0	10.1	11.2	10.6			10.1

DIAGRAM OF CYLINDERS 1, 2, AND 5.

Scale : 1 inch = 1 foot.



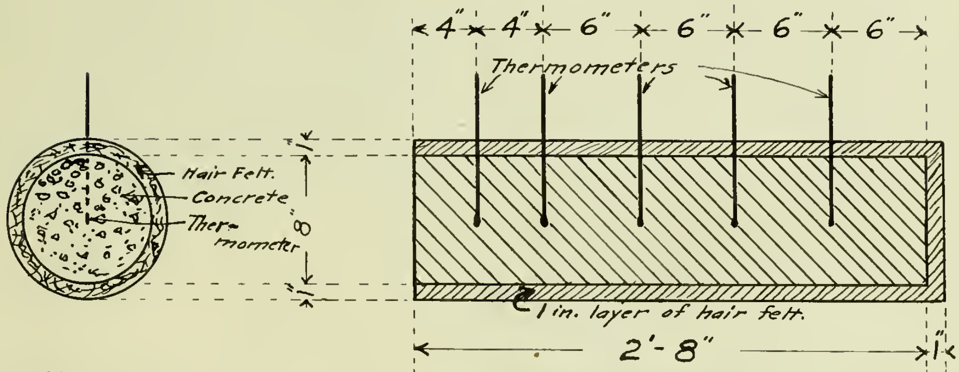
TOP VIEW WITH COVER REMOVED.



SIDE VIEW.

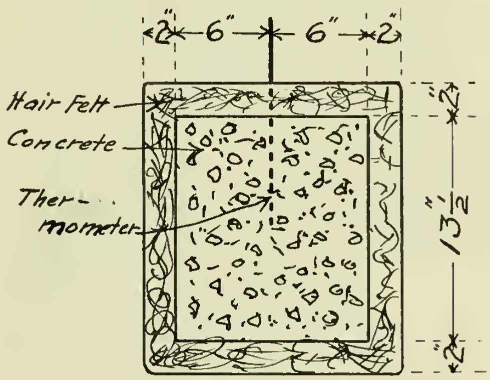
DIAGRAMS OF BEAM AND OF CYLINDERS 3 AND 4.

Scale: 1 inch = 1 foot.

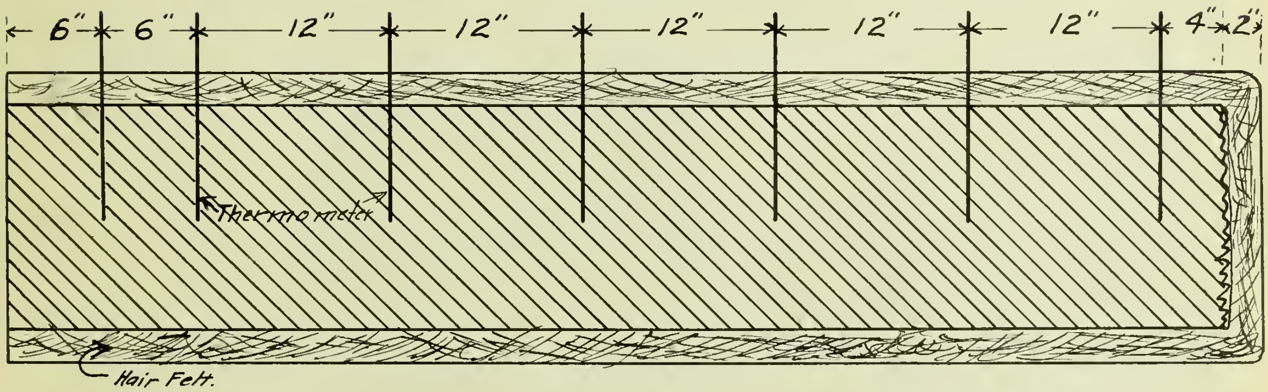


END VIEW LONGITUDINAL SECTION.

CYLINDERS 3 AND 4.



END VIEW OF BEAM.



LONGITUDINAL SECTION OF BEAM.

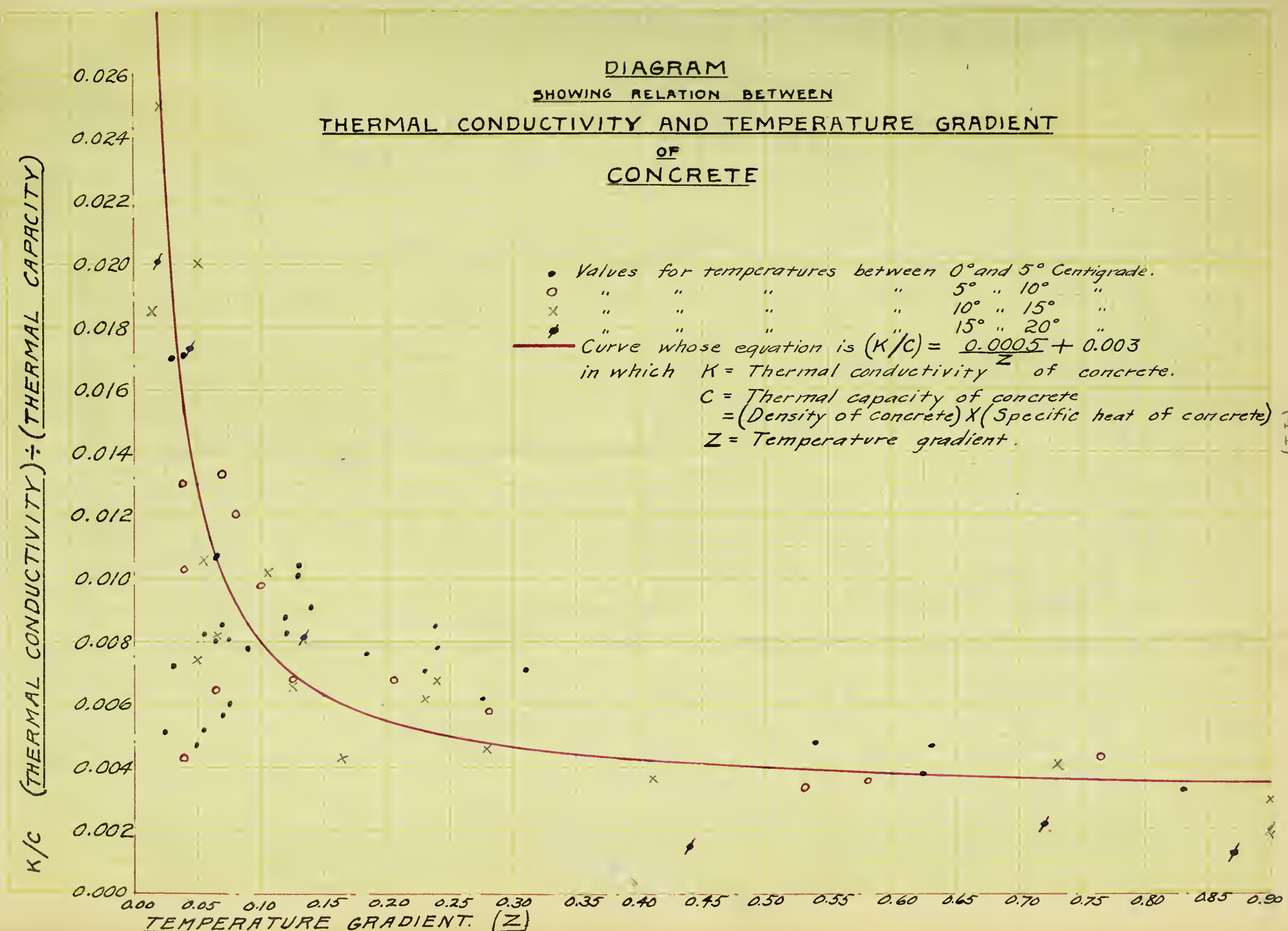
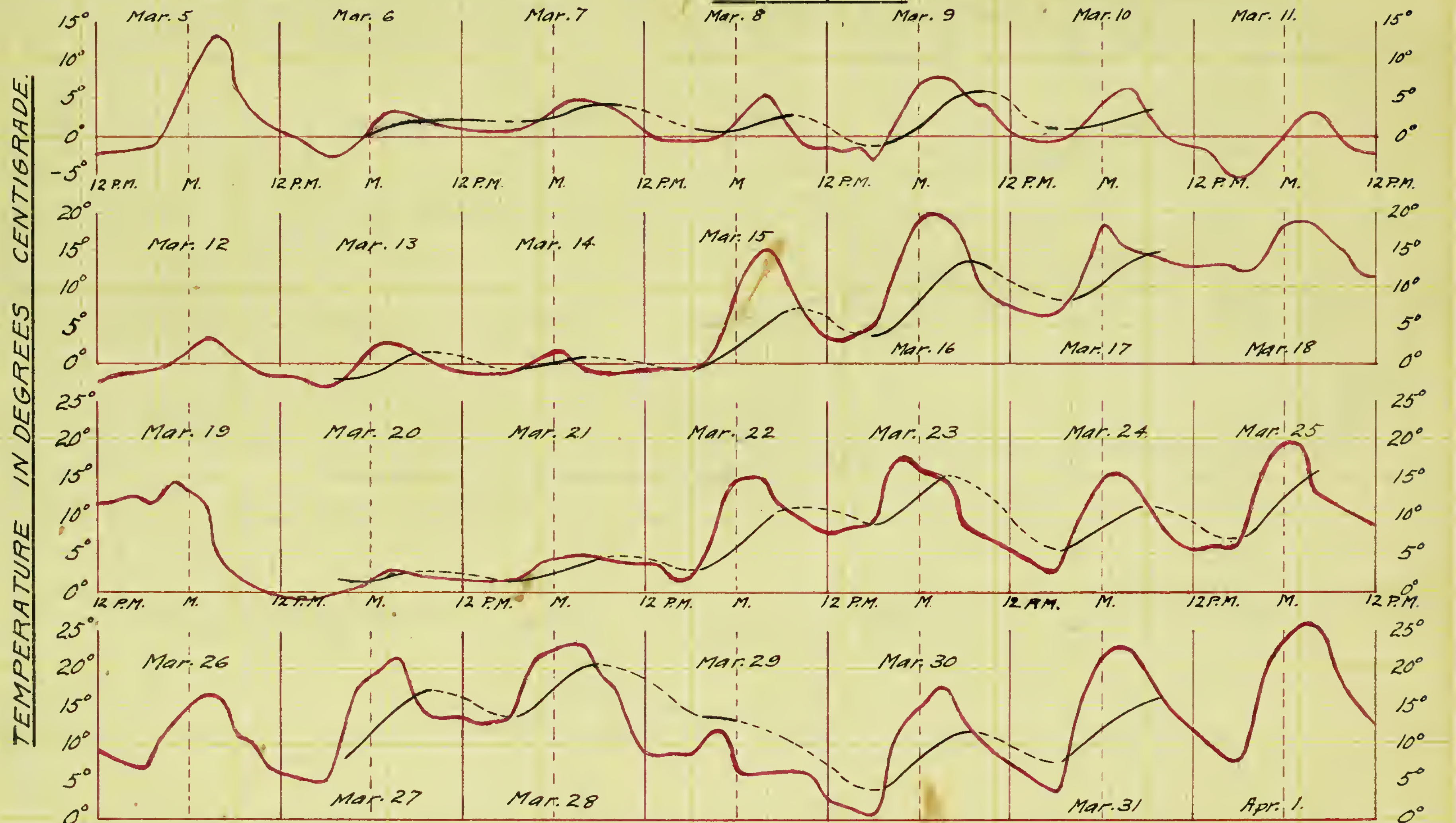


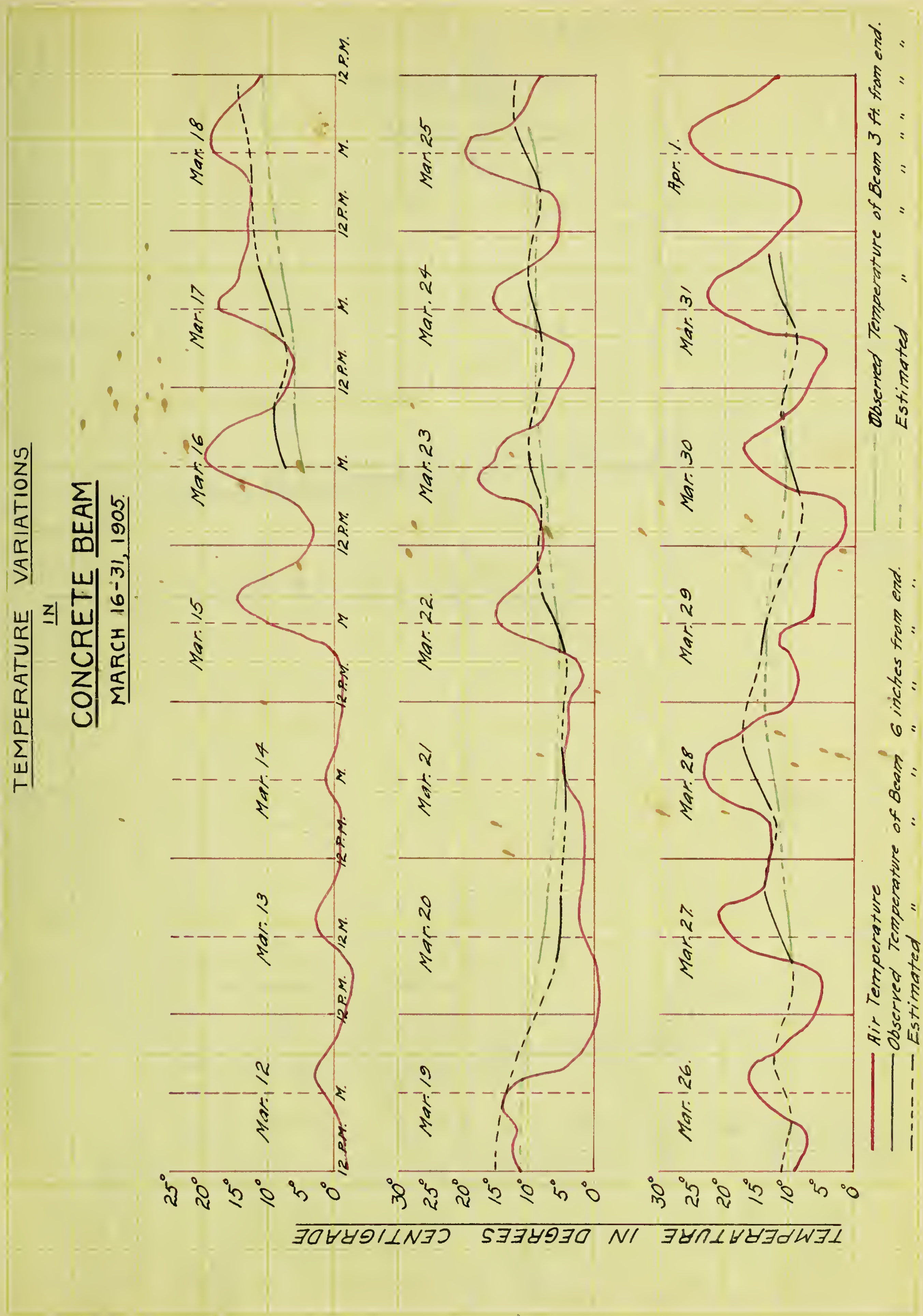
DIAGRAM
SHOWING RELATION BETWEEN
THERMAL CONDUCTIVITY AND TEMPERATURE GRADIENT
OF
CONCRETE
• Values for temperatures between 0° and 5° Centigrade.
o " " " " 5° " 10° "
x " " " " 10° " 15° "
" " " " 15° " 20° "
Curve whose equation is (K/C) = 0.0005/Z + 0.003
in which K = Thermal conductivity of concrete.
C = Thermal capacity of concrete
= (Density of concrete) X (Specific heat of concrete)
Z = Temperature gradient.
K/C (THERMAL CONDUCTIVITY) ÷ (THERMAL CAPACITY)
0.026
0.024
0.022
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70 0.75 0.80 0.85 0.90
TEMPERATURE GRADIENT (Z)

TEMPERATURE VARIATIONS IN CYLINDER NO. 1 DURING MARCH, 1905.

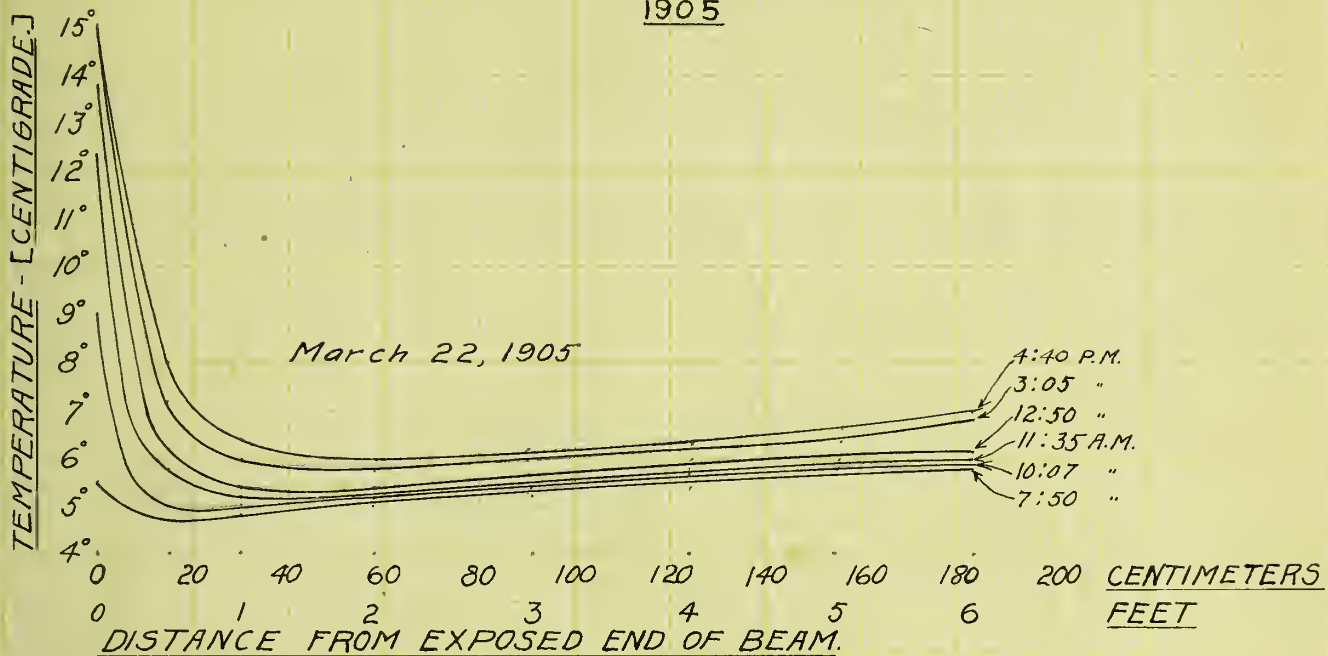


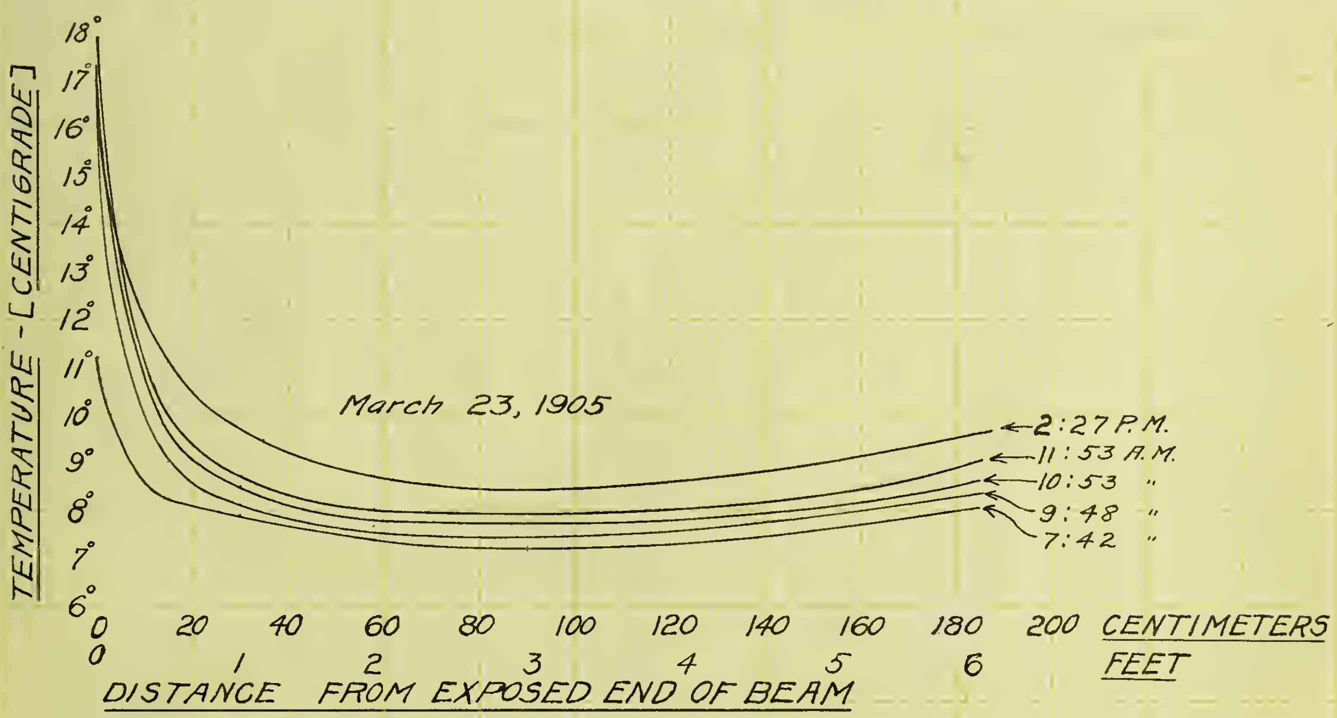
Air Temperature.
Observed Temperature at Center of Cylinder.
Estimated " " " " "

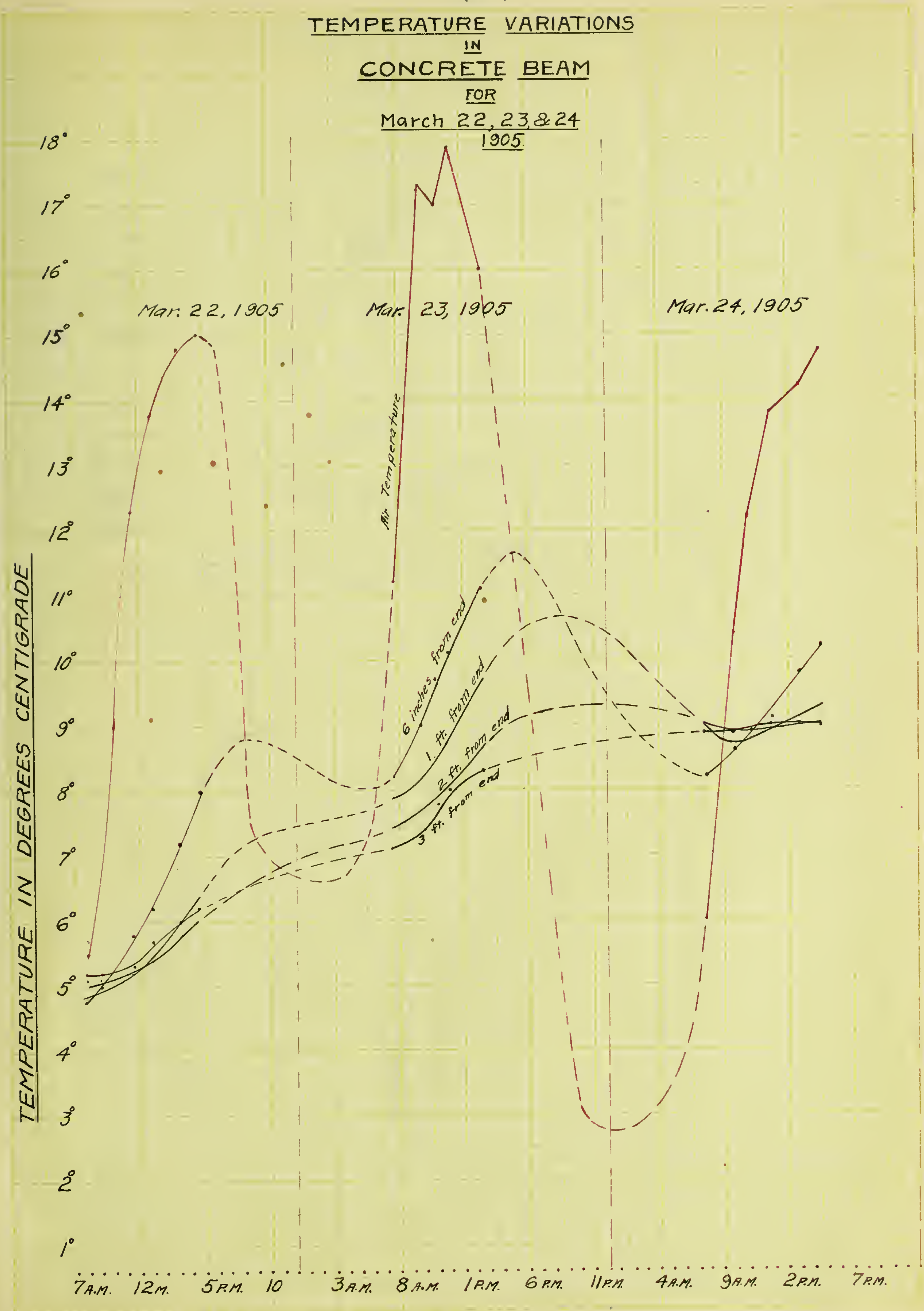
Concrete :- 1 cement : 3 sand : 6 broken stone.
Cylinder : Diameter = 17.5 inches. Length = 3 ft. 6 in.


TEMPERATURE VARIATIONS
IN
CONCRETE BEAM
MARCH 16-31, 1905.
TEMPERATURE IN DEGREES CENTIGRADE
Mar. 12
Mar. 13
Mar. 14
Mar. 15
Mar. 16
Mar. 17
Mar. 18
Mar. 19
Mar. 20
Mar. 21
Mar. 22
Mar. 23
Mar. 24
Mar. 25
Mar. 26.
Mar. 27
Mar. 28
Mar. 29
Mar. 30
Mar. 31
Apr. 1.
12 P.M.
M.
12 M.
0°
5°
10°
15°
20°
25°
30°
Air Temperature
Observed Temperature of Beam 6 inches from end.
Estimated " " " " " "
Observed Temperature of Beam 3 ft. from end.
Estimated " " " " " "

TEMPERATURE CURVES
FOR
CONCRETE BEAM
FOR
March 22 & 23
1905






TEMPERATURE VARIATIONS
IN
CONCRETE BEAM
FOR
March 22, 23 & 24
1905
Mar. 22, 1905
Mar. 23, 1905
Mar. 24, 1905
Air Temperature
6 inches from end
1 ft. from end
2 ft. from end
3 ft. from end
TEMPERATURE IN DEGREES CENTIGRADE
18°
17°
16°
15°
14°
13°
12°
11°
10°
9°
8°
7°
6°
5°
4°
3°
2°
1°
7 A.M.
12 M.
5 P.M.
10
3 A.M.
8 A.M.
1 P.M.
6 P.M.
11 P.M.
4 A.M.
9 A.M.
2 P.M.
7 P.M.

TEMPERATURE GRADIENT CURVES FOR CONCRETE BEAM

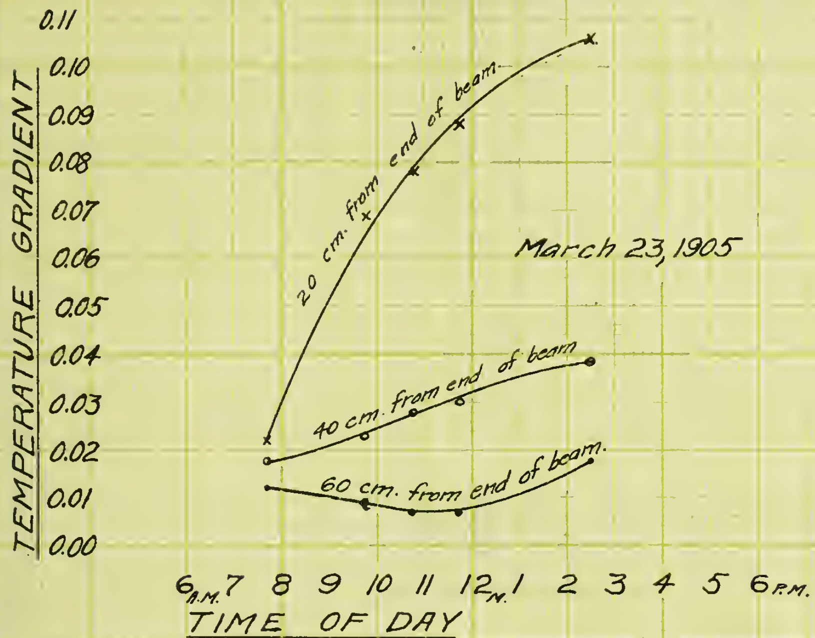
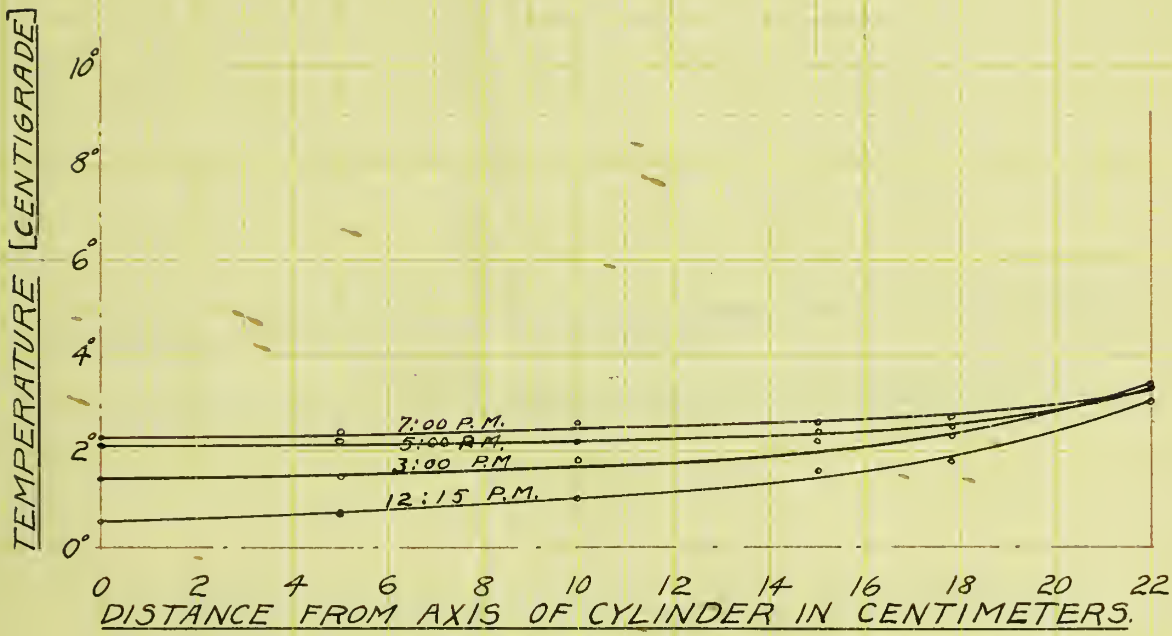
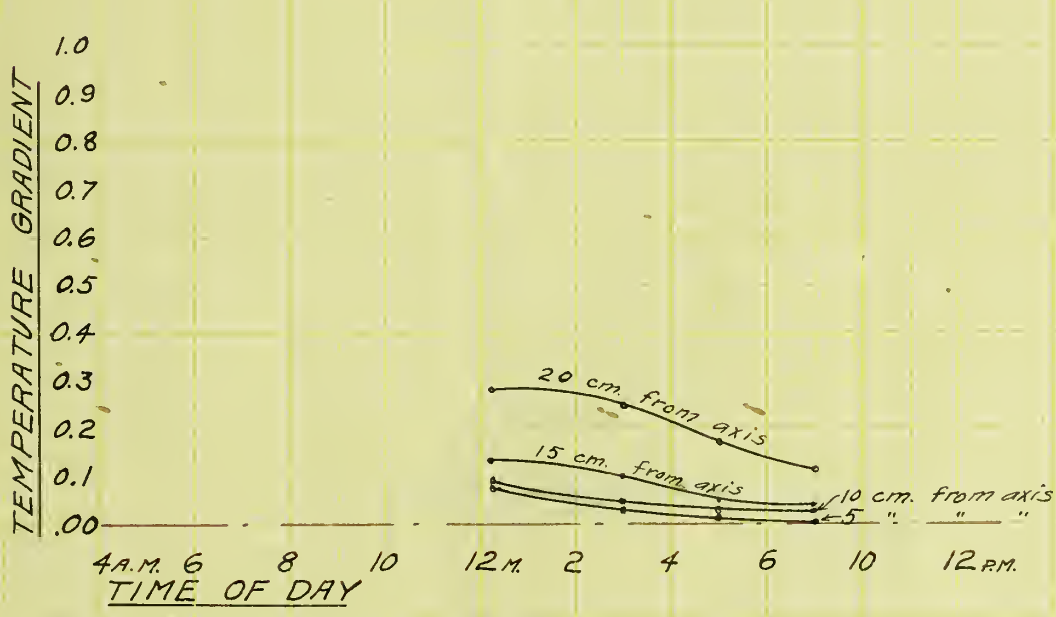


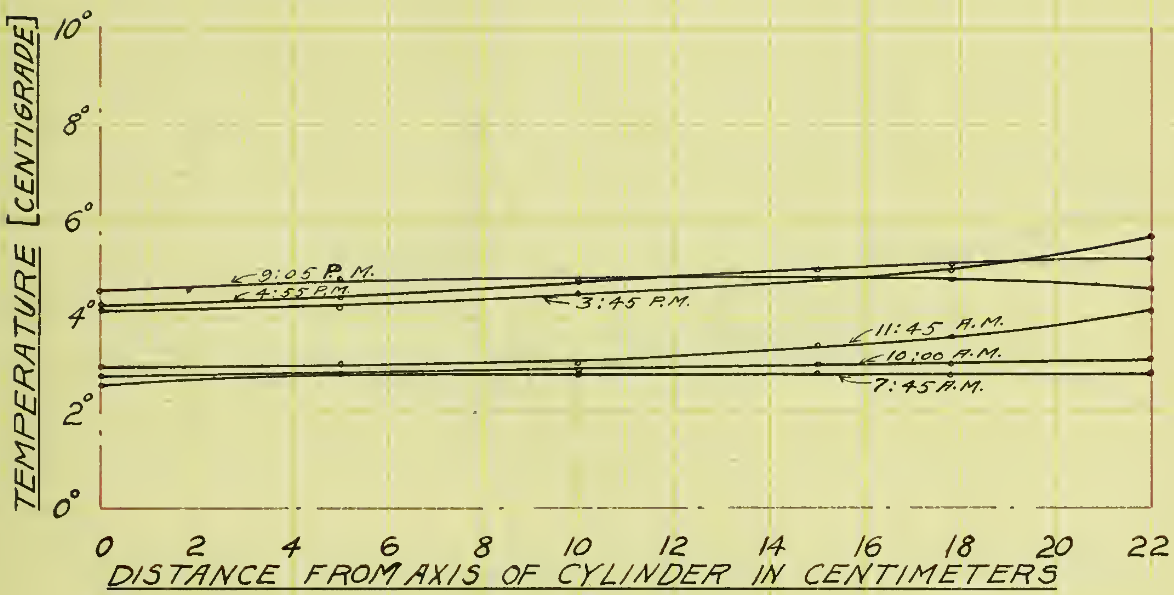
Plate VII.

TEMPERATURE CURVES FOR CYLINDER NO. 1. FOR March 6, 1905.





TEMPERATURE CURVES
FOR
CYLINDER NO. 1.
FOR
March 7, 1905



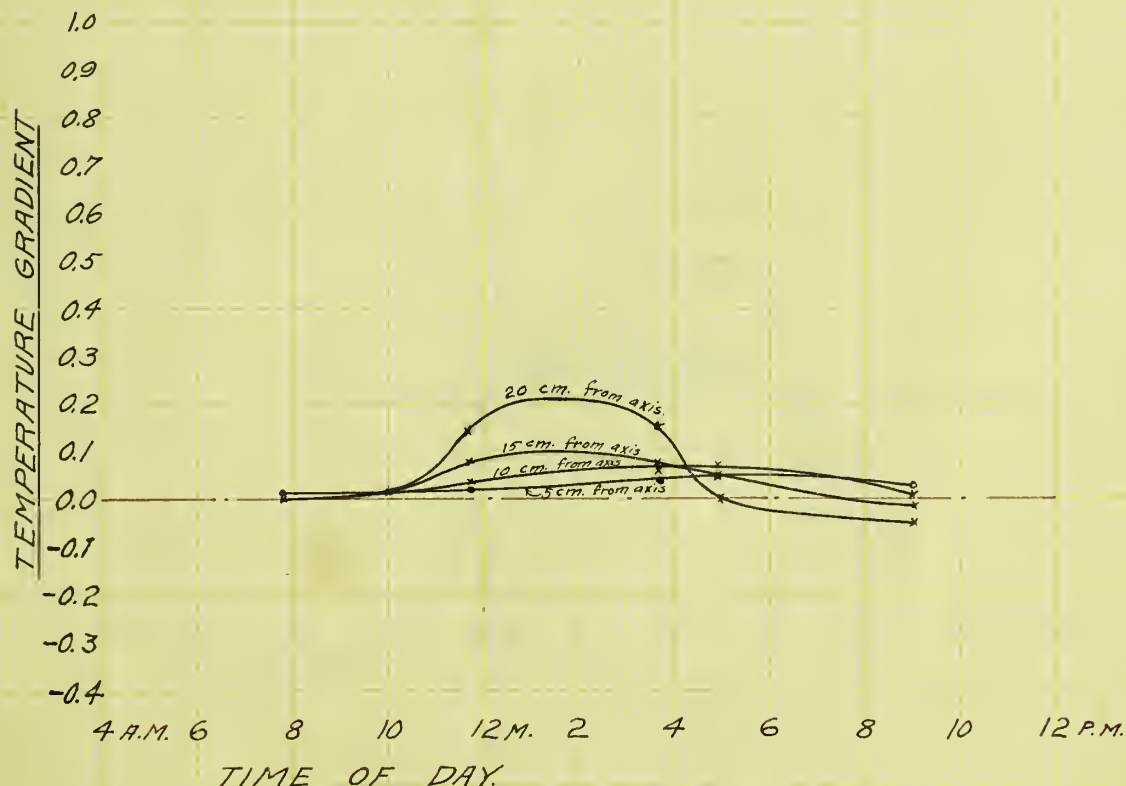
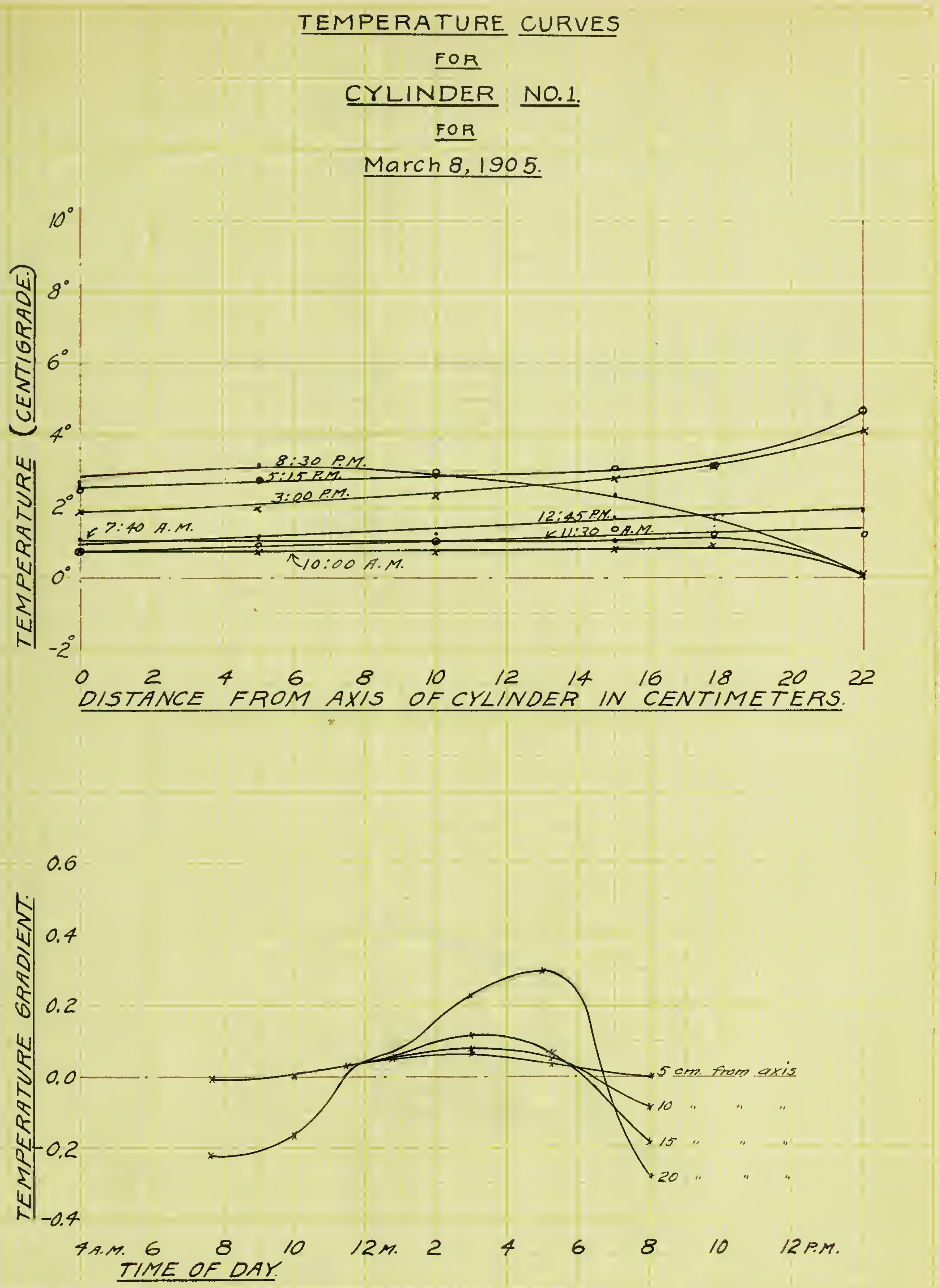
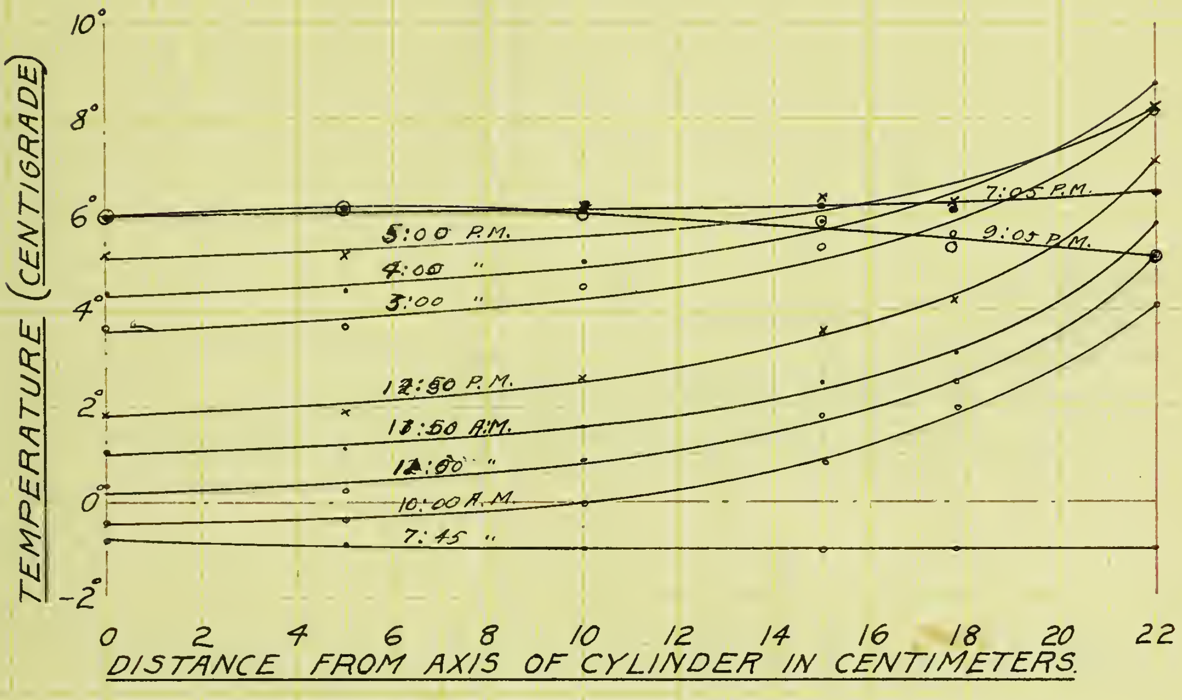
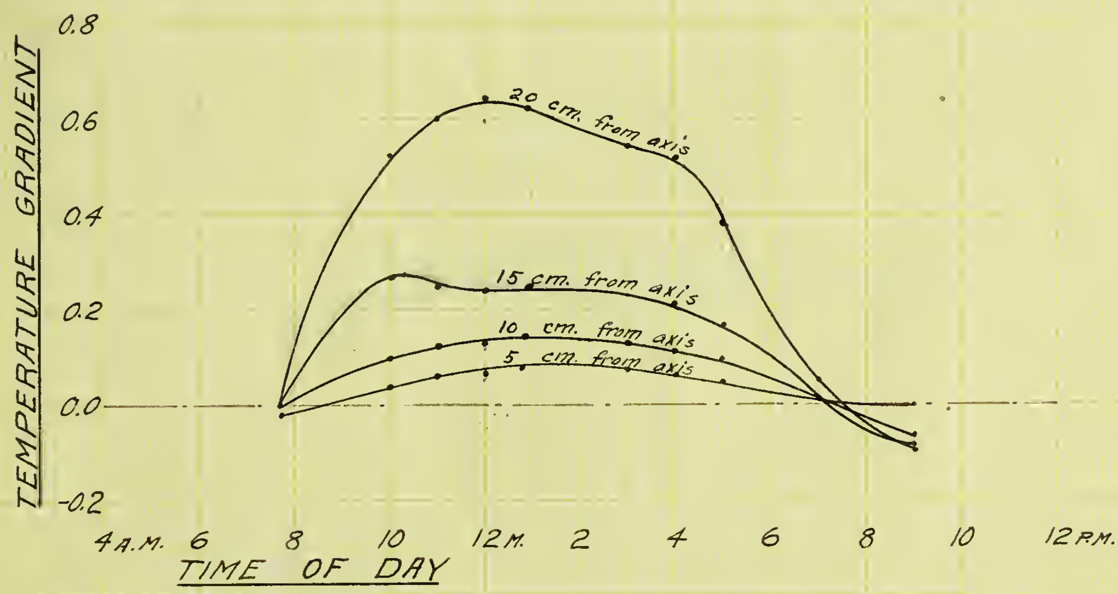


Plate IX


TEMPERATURE CURVES
FOR
CYLINDER NO. 1.
FOR
March 8, 1905.
TEMPERATURE (CENTIGRADE.)
10°
8°
6°
4°
2°
0°
-2°
8:30 P.M.
5:15 P.M.
3:00 P.M.
7:40 A.M.
10:00 A.M.
12:45 P.M.
11:30 A.M.
0
2
4
6
8
10
12
14
16
18
20
22
DISTANCE FROM AXIS OF CYLINDER IN CENTIMETERS.
TEMPERATURE GRADIENT.
0.6
0.4
0.2
0.0
-0.2
-0.4
5 cm. from axis
10 " "
15 " "
20 " "
4 A.M.
6
8
10
12 M.
2
4
6
8
10
12 P.M.
TIME OF DAY.

TEMPERATURE CURVES FOR CYLINDER NO. 1 FOR March 9, 1905.





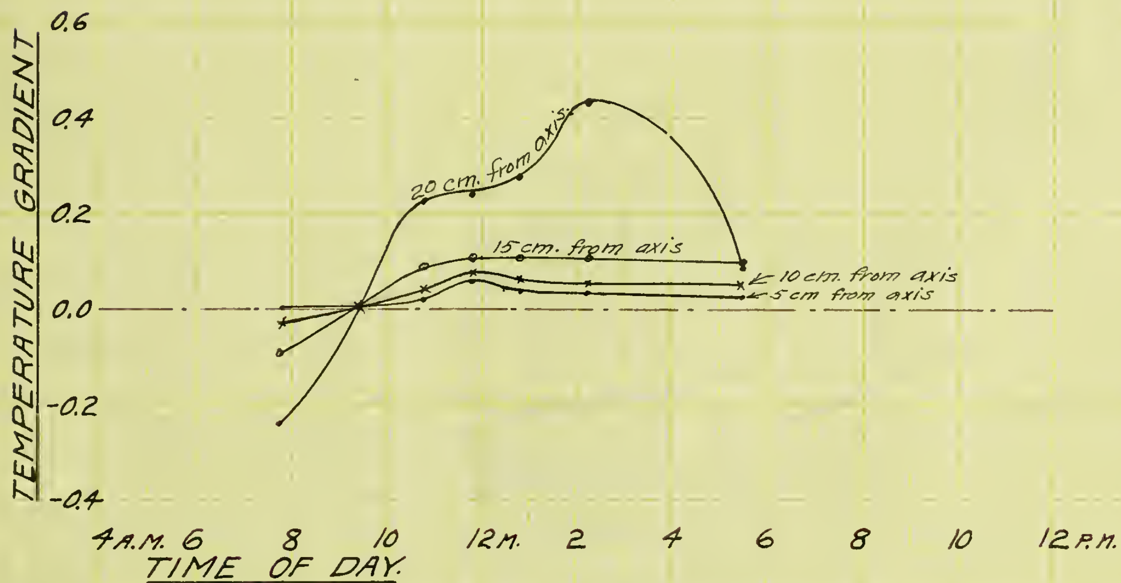
TEMPERATURE CURVES

FOR

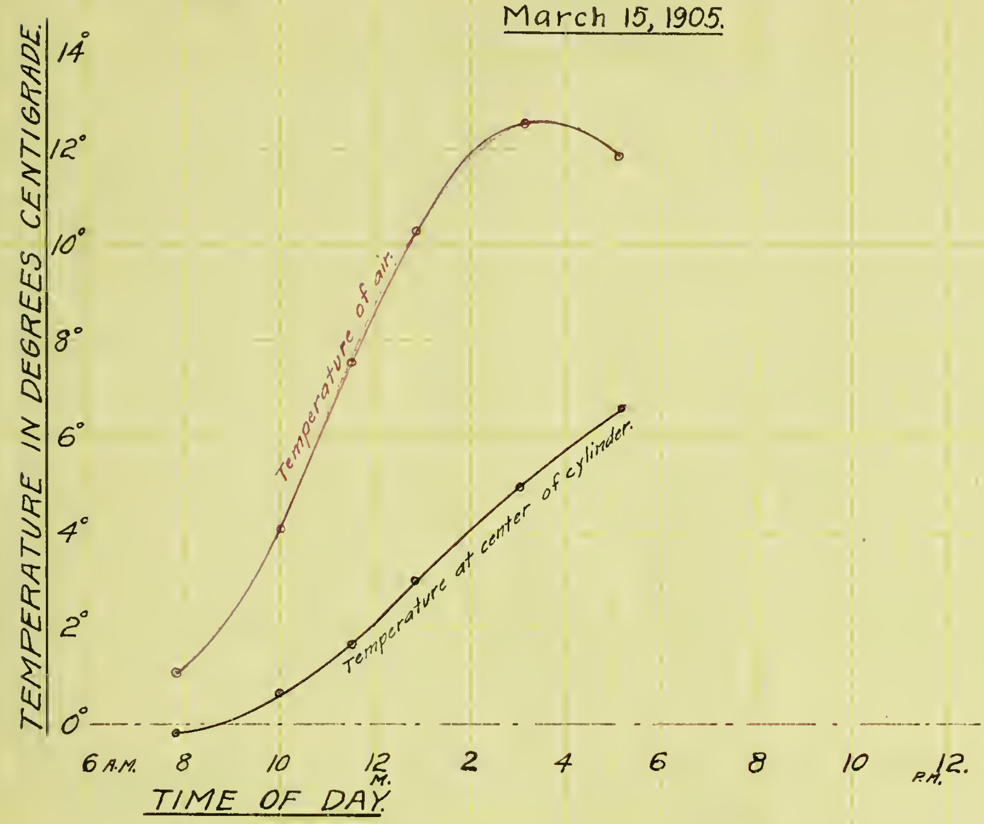
CYLINDER NO. 1

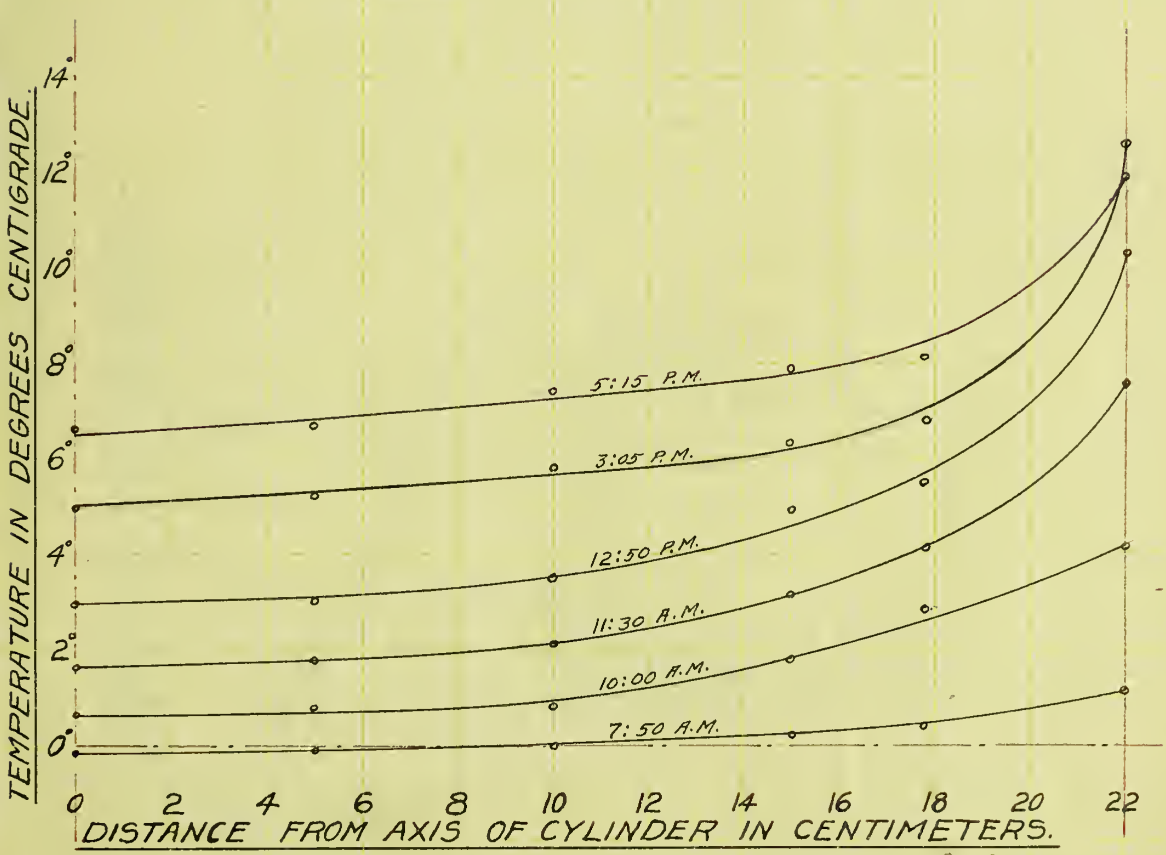
FOR

March 10, 1905

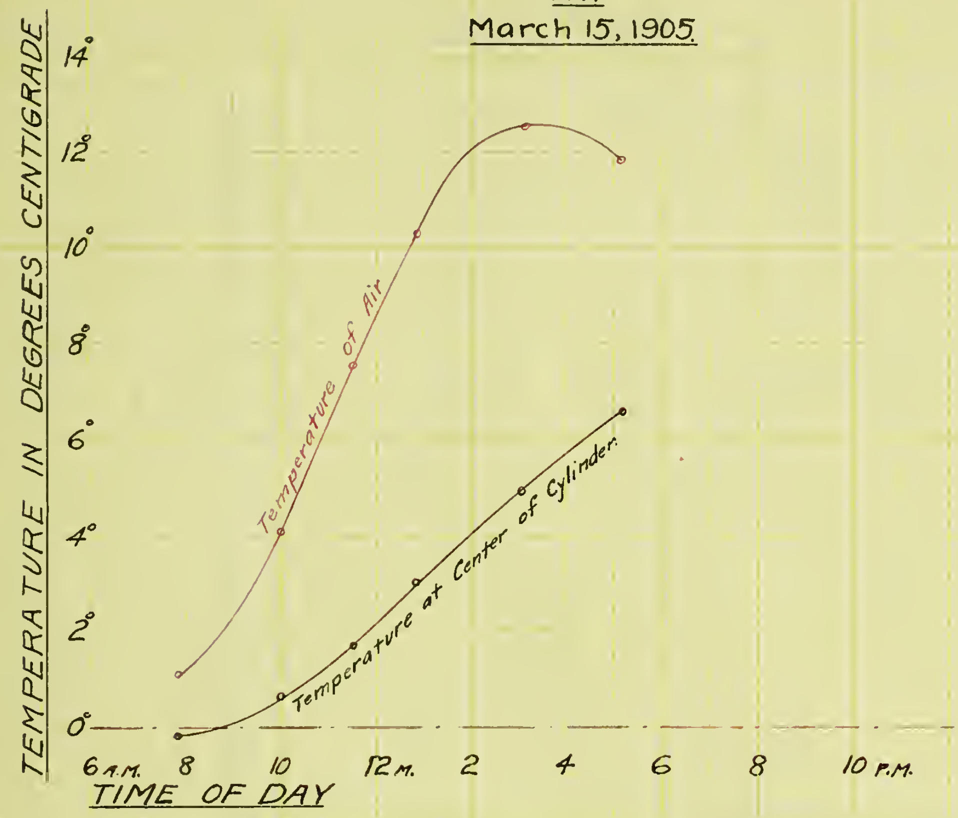


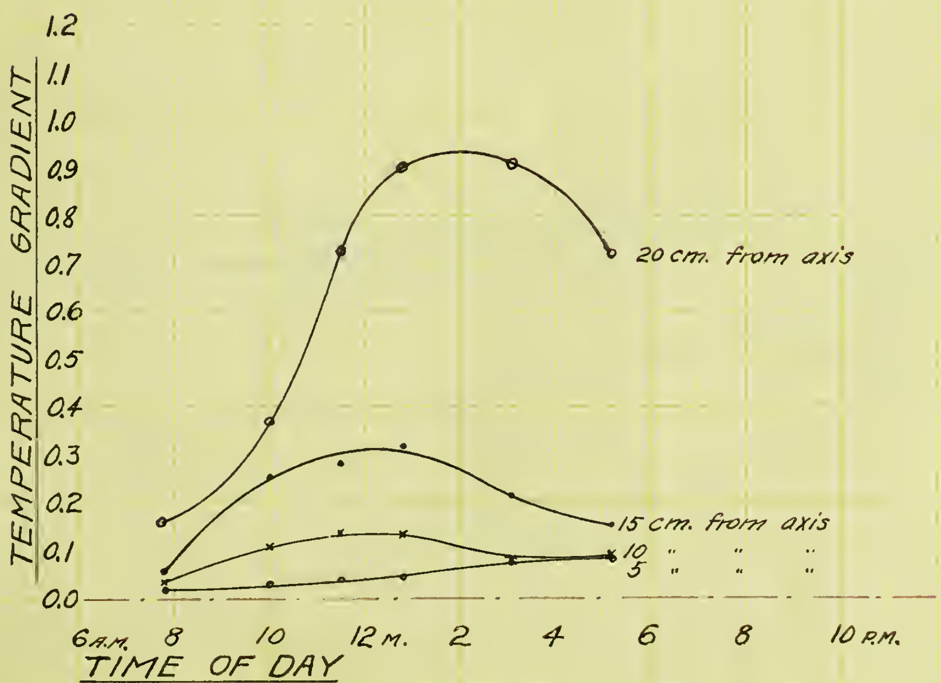
TEMPERATURE VARIATIONS IN CYLINDER NO. 1. FOR March 15, 1905.





TEMPERATURE GRADIENT CURVES
FOR
CYLINDER NO. 1
FOR
March 15, 1905.



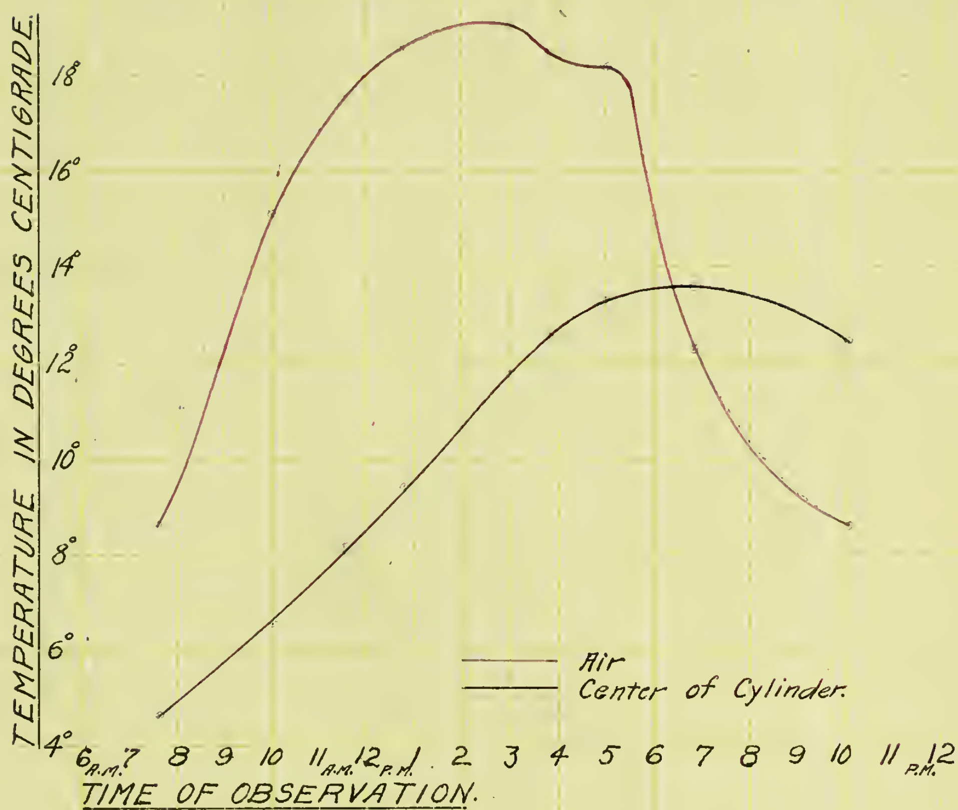


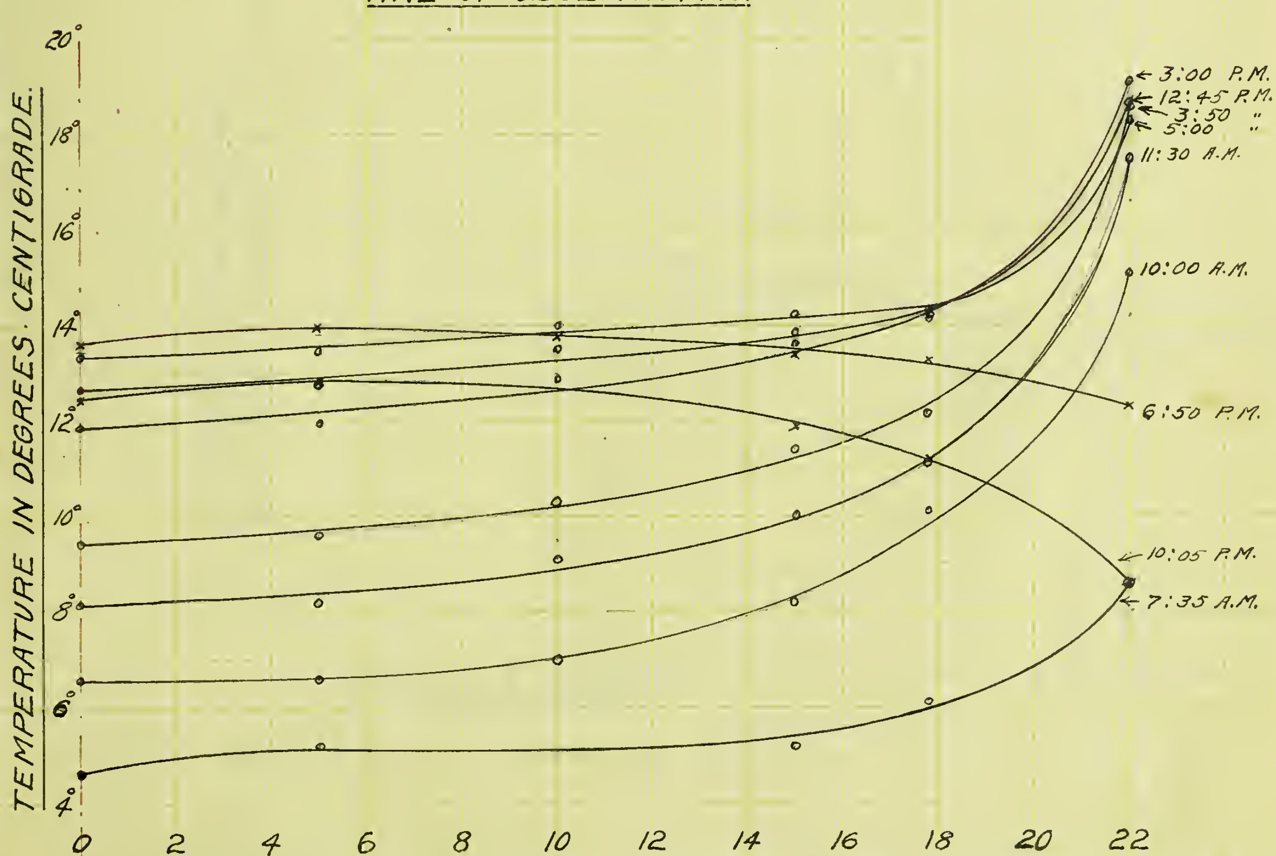
TEMPERATURE VARIATIONS IN

CYLINDER NO. 1.

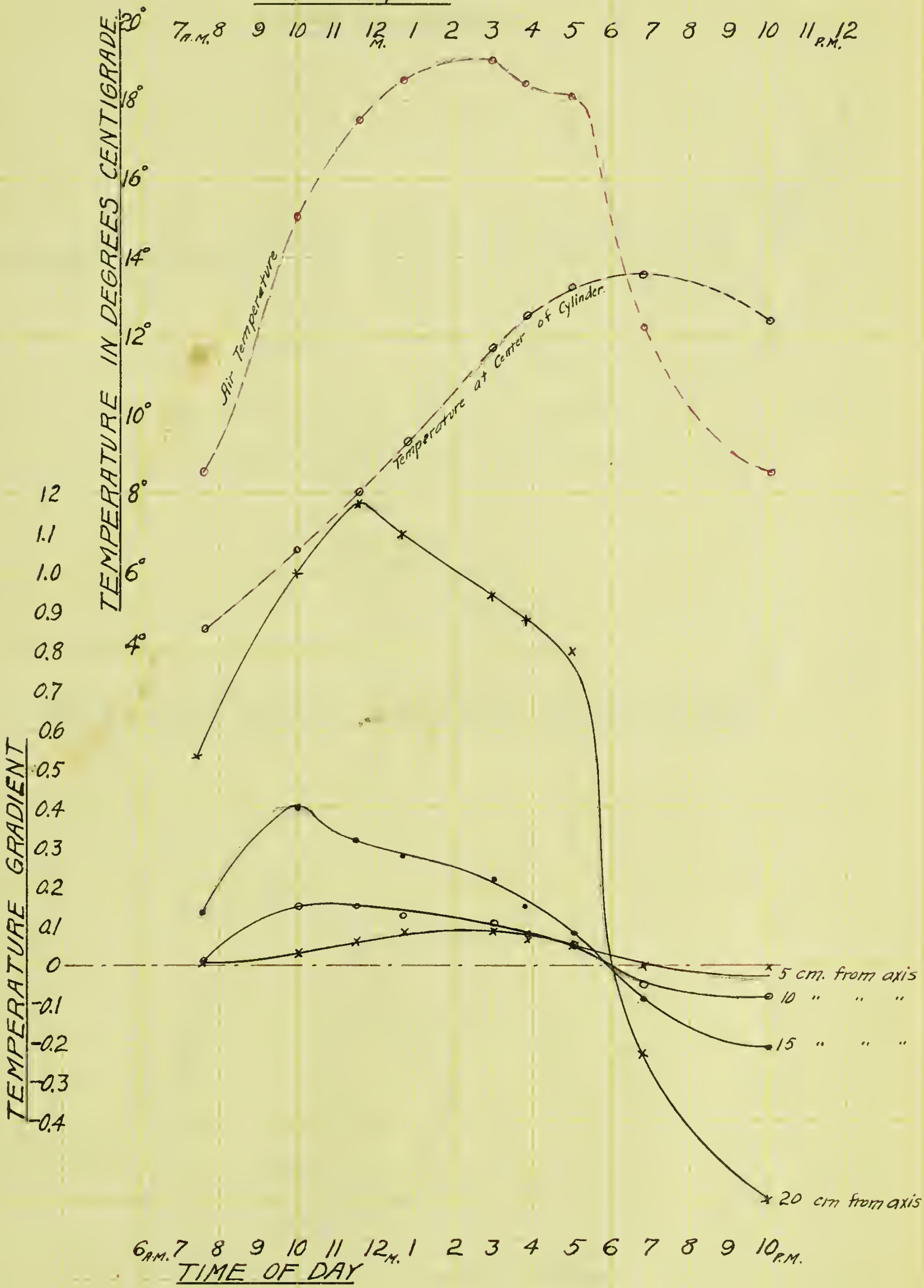
FOR

March 16, 1905.





TEMPERATURE GRADIENT CURVES
FOR
CYLINDER NO. 1.
FOR
March 16, 1905



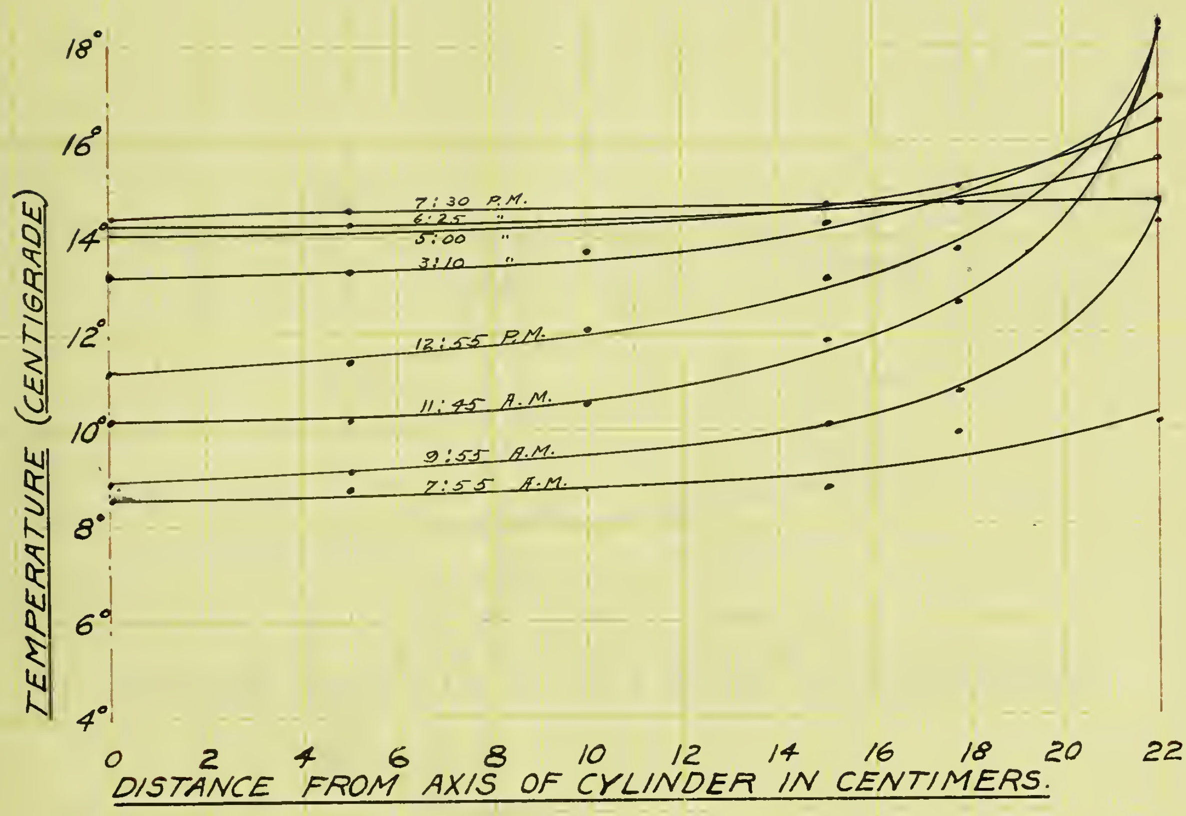
TEMPERATURE CURVES

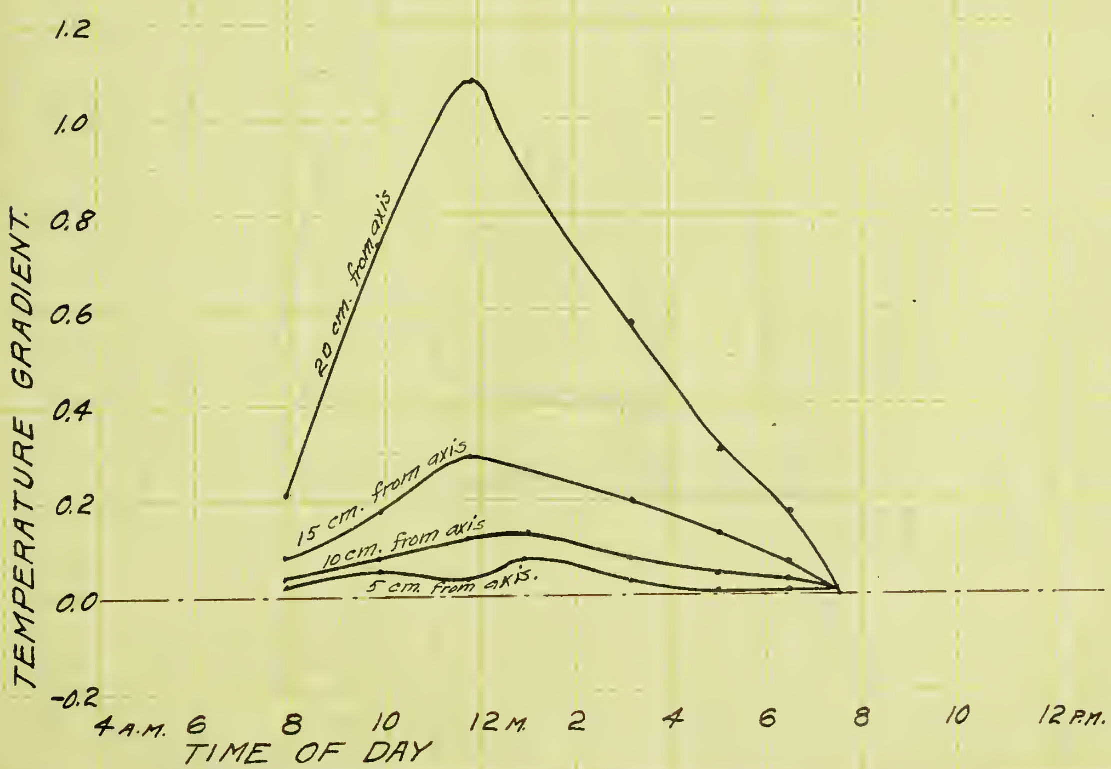
FOR

CYLINDER NO. 1.

FOR

March 17, 1905.





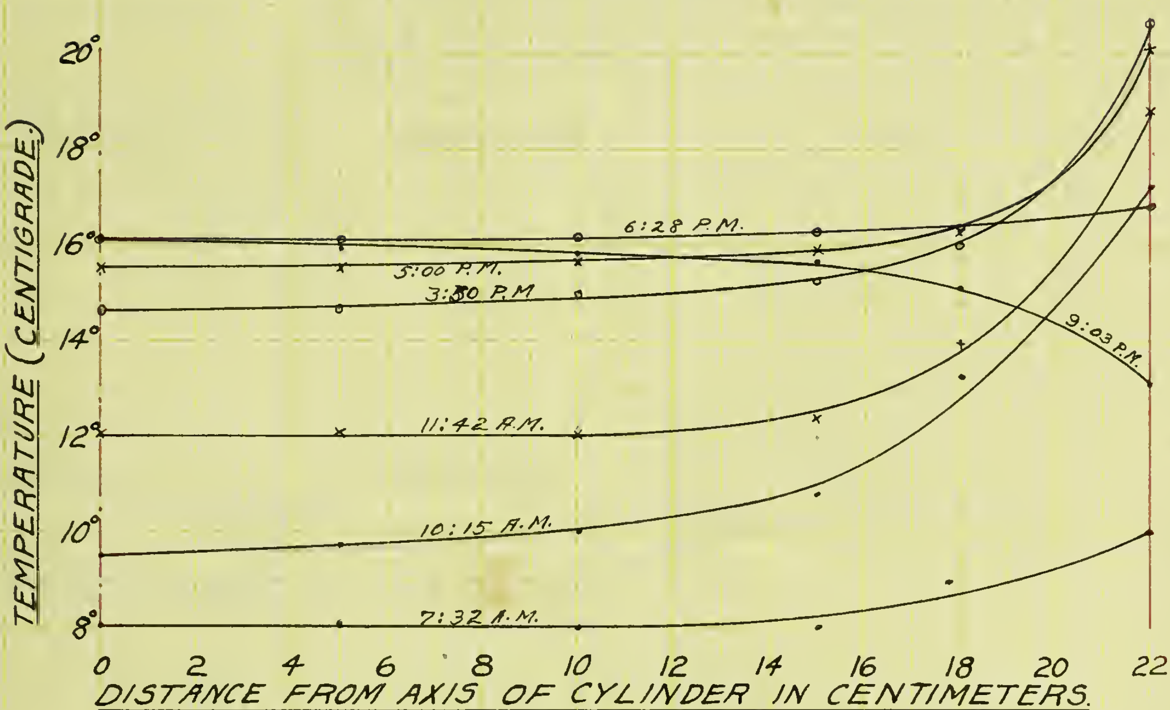
TEMPERATURE CURVES

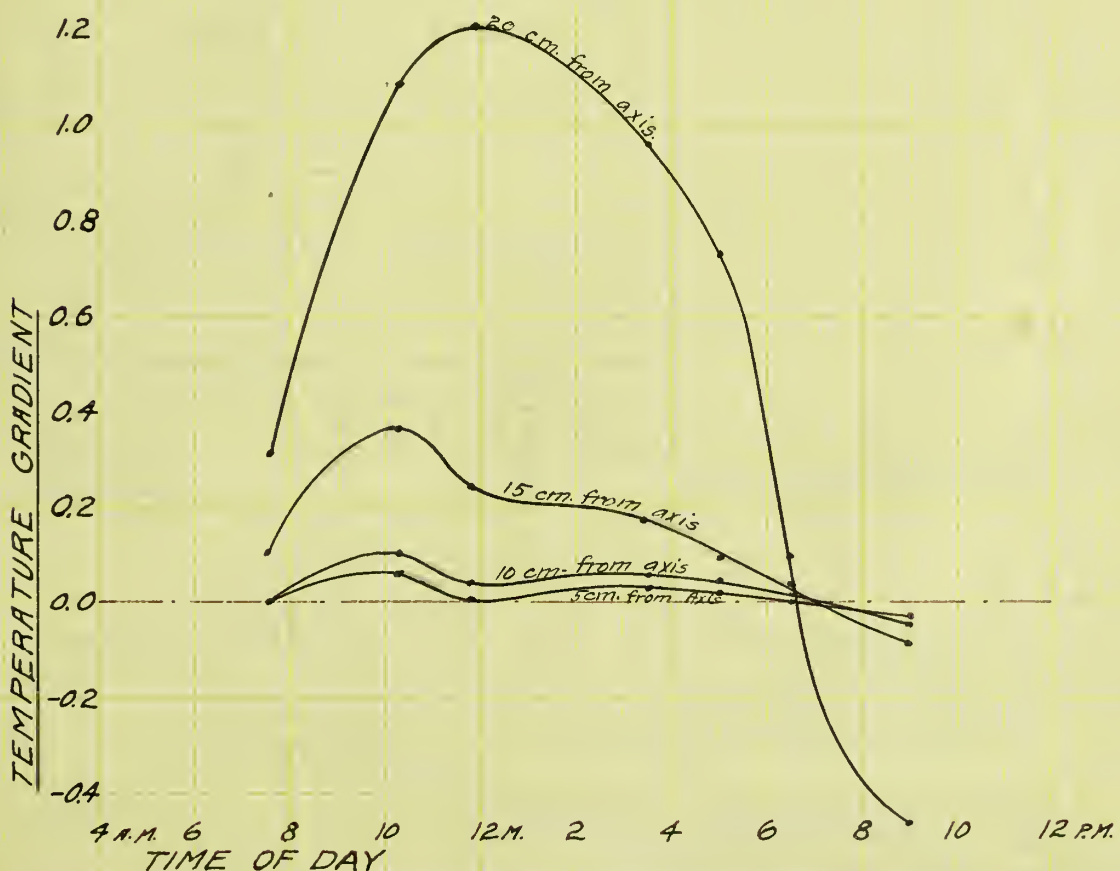
FOR

CYLINDER NO. 1.

FOR

March 31, 1905





[illegible]

[illegible]

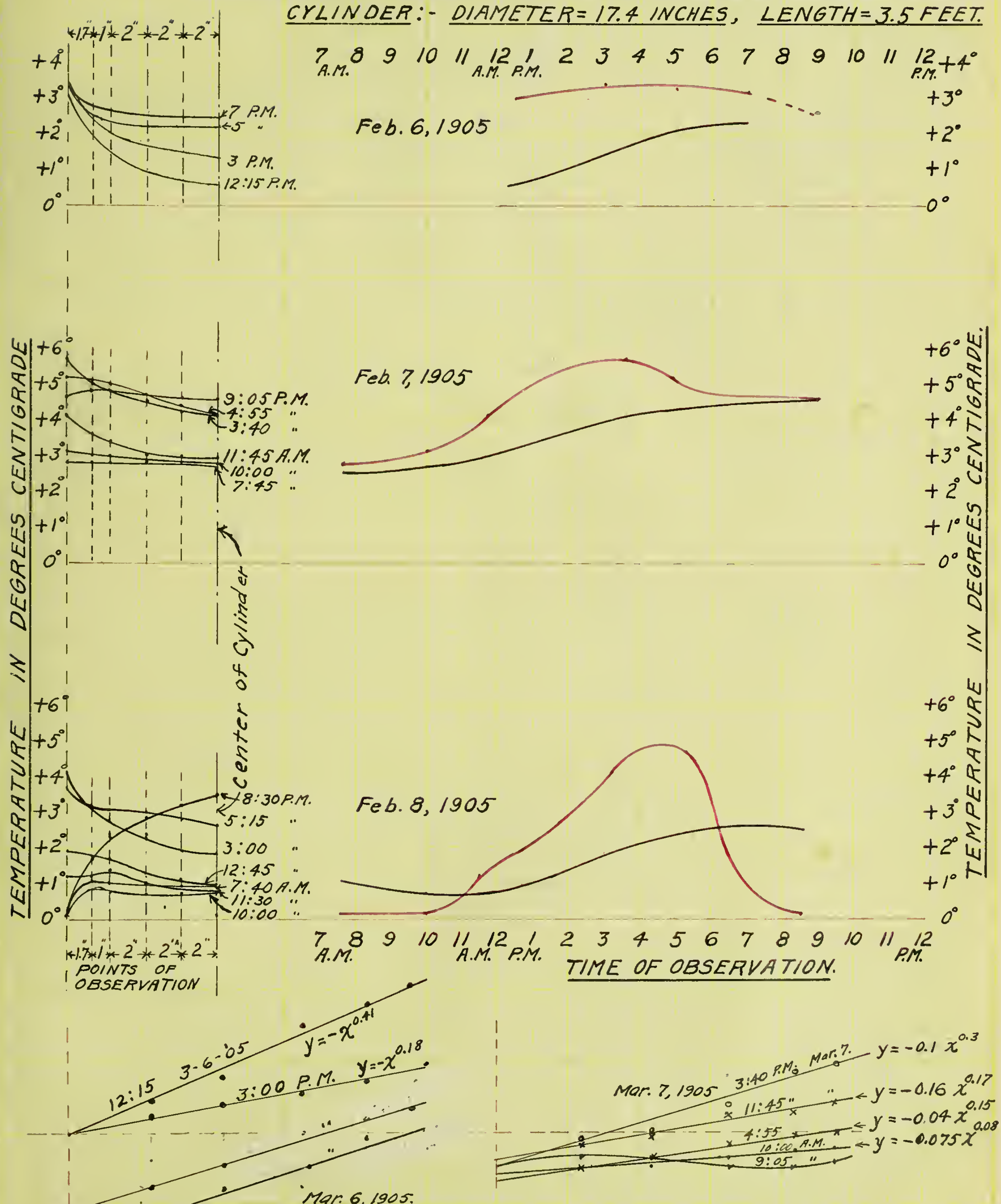
[illegible]

[illegible]

TEMPERATURE VARIATIONS IN CYLINDER NO. 1

CONCRETE :- 1 CEMENT : 3 SAND : 6 BROKEN STONE

CYLINDER :- DIAMETER = 17.4 INCHES, LENGTH = 3.5 FEET.



LOGARITHMIC TEMPERATURE CURVES.

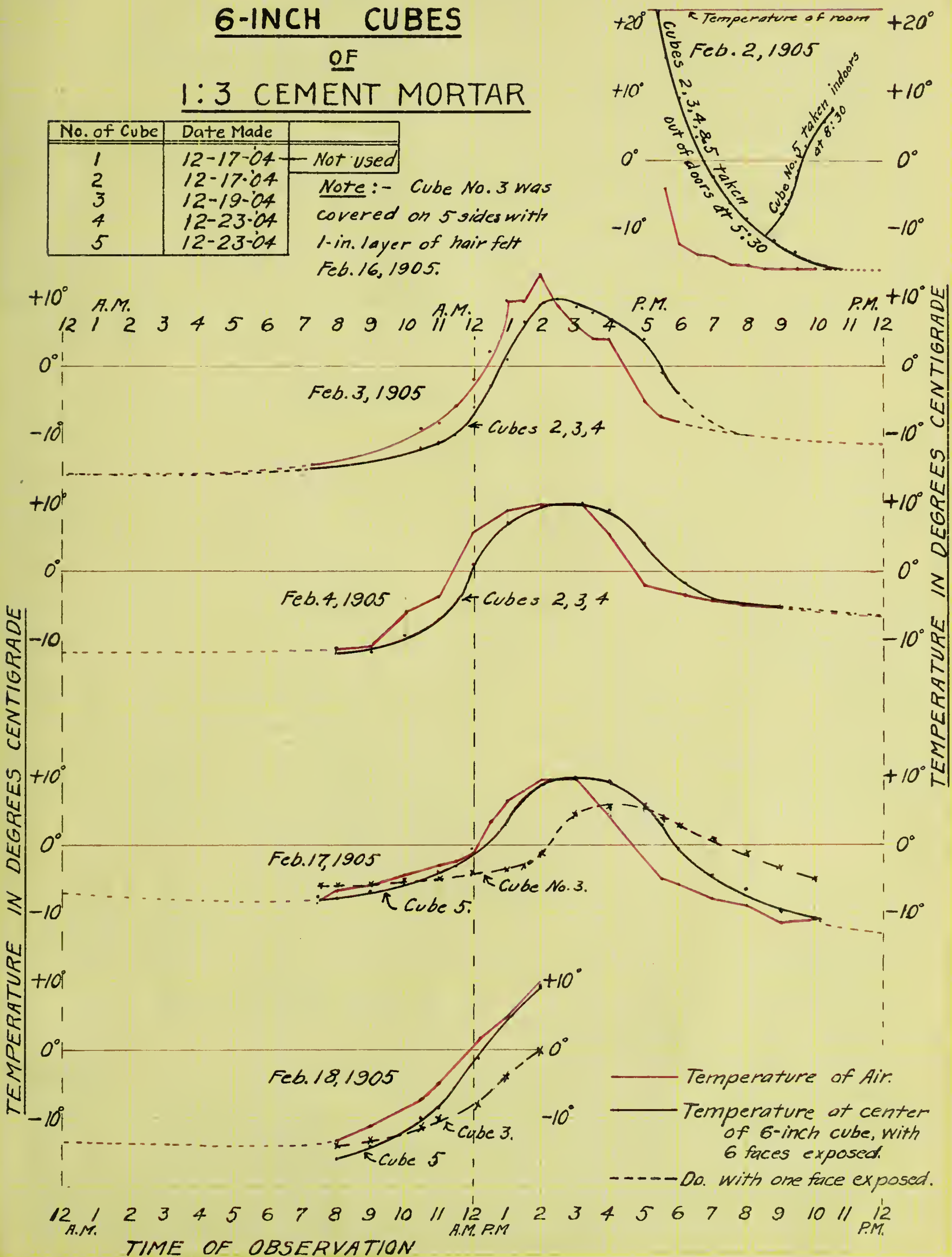
y = Temperature of concrete minus temperature of air in degrees centigrade.

x = Distance from surface of cylinder to point of observation, in inches

TEMPERATURE VARIATIONS IN 6-INCH CUBES OF 1:3 CEMENT MORTAR

No. of Cube	Date Made	
1	12-17-04	Not used
2	12-17-04	
3	12-19-04	
4	12-23-04	
5	12-23-04	

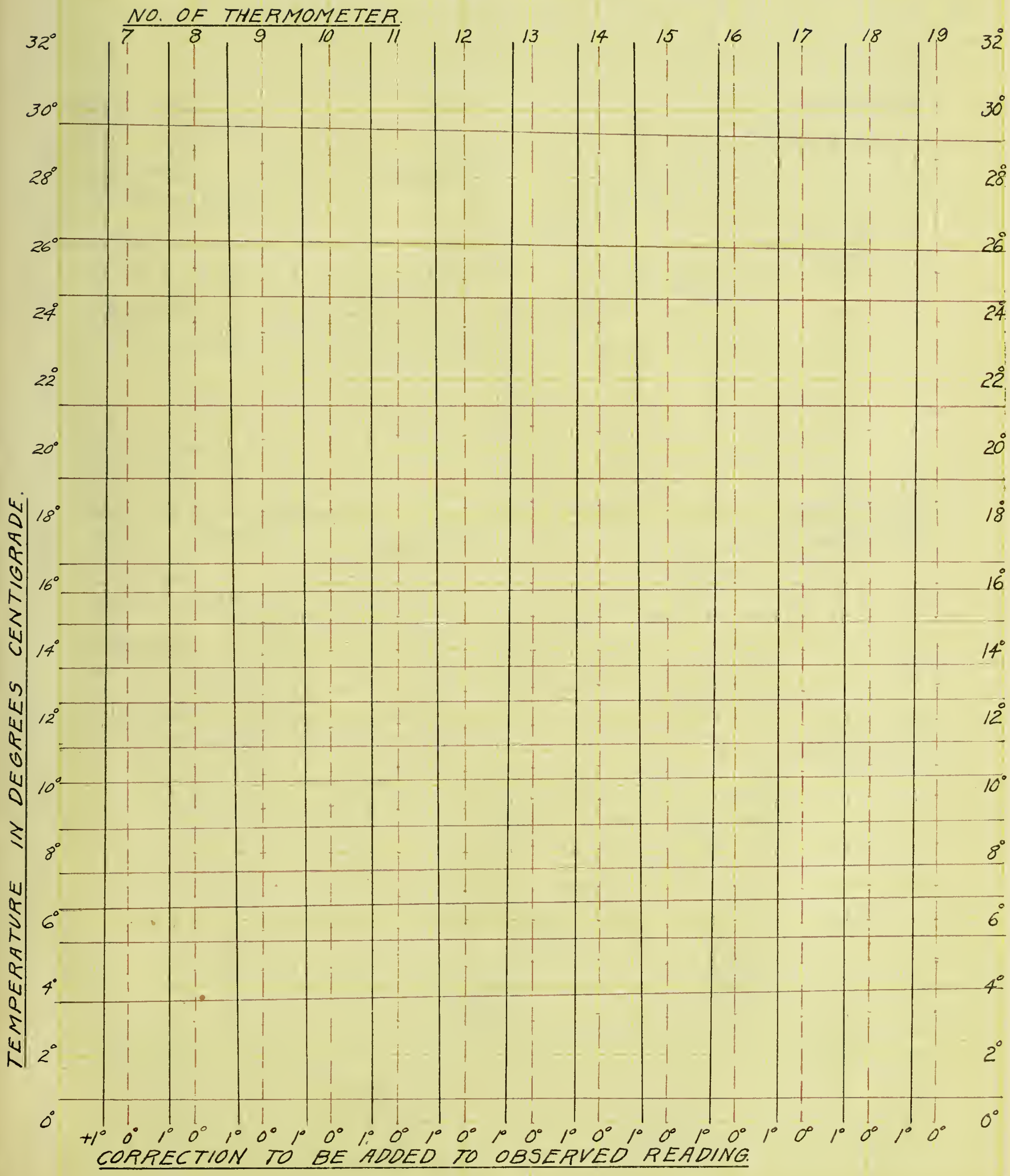
Note:- Cube No. 3 was covered on 5 sides with 1-in. layer of hair felt Feb. 16, 1905.



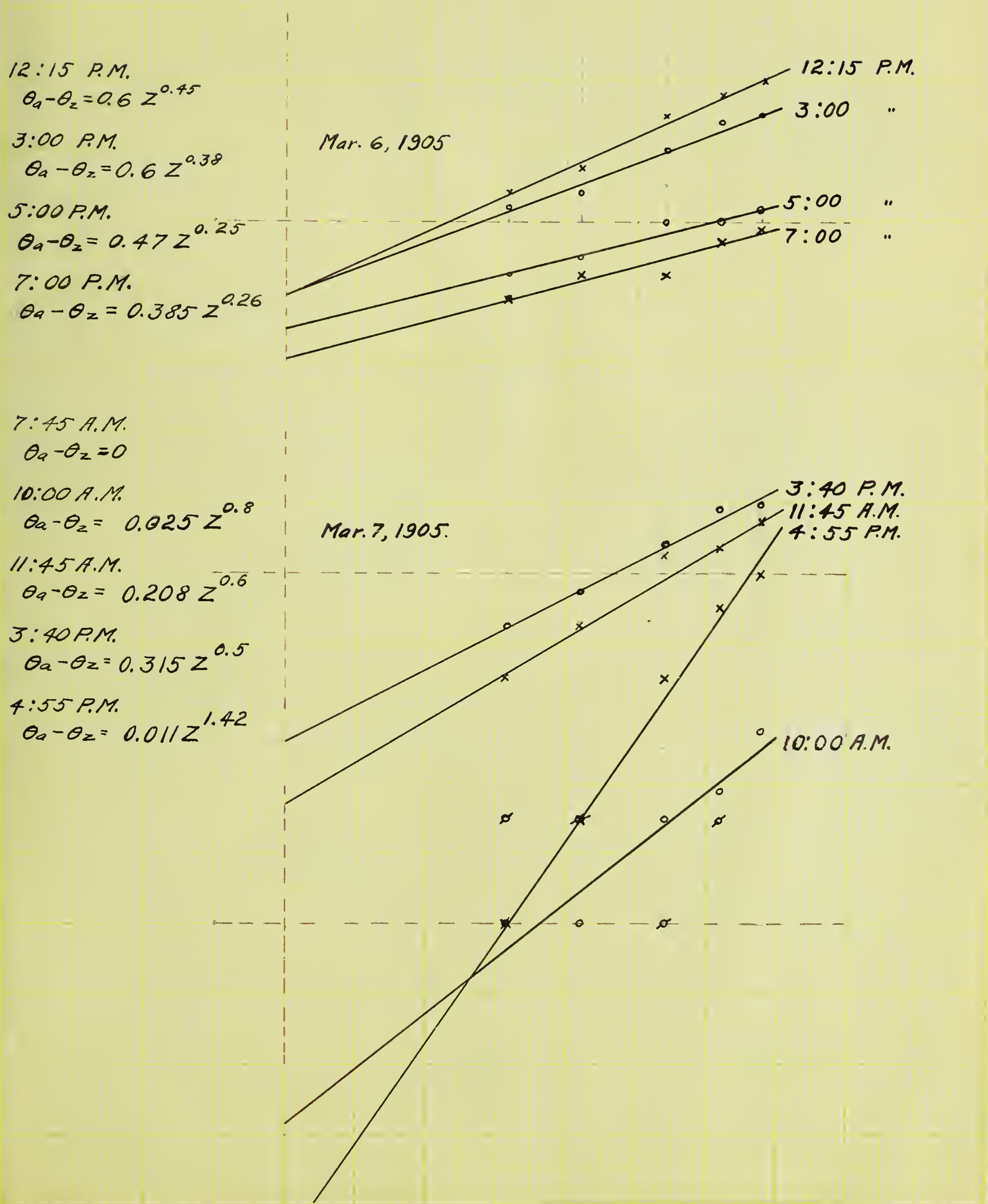
CALIBRATION DIAGRAM

FOR

THERMOMETERS 7-19



LOGARITHMIC TEMPERATURE CURVES
FOR
CYLINDER NO. 1.



APPENDIX.

DATA AND CONSTANTS PERTAINING TO TEMPERATURE CHANGES IN VARIOUS MATERIALS.

Loss of Heat from Bodies in Contact with Air.

The following expressions for the loss of heat from bodies in contact with air, are given in "Sewage Disposal in the United States" by Rafter and Baker, page 314.

$L = 0.1\ F(t-T)^{1.2}$ in which L is the loss of heat (B.T.U.) by contact per square foot per hour; F is a factor for movement of air = 4 for quiet air, 5 for moderately moving air, and 6 for rapidly moving air; t is the temperature of the heated body, in degrees F.; and T is the temperature of the air in contact, in degrees F.

When (t-T) does not exceed 20 to 30 degrees F. we may take $L = 0.1\ F(t-T)$.

Relative Rates of Cooling of Soils.

The following table, taken from "Sewage Disposal in the United States" by Rafter and Baker, page 311, gives the results of some experiments by Professor Schübler, of the University of Tubingen, on the relative rates of cooling of various soils.

Material	Time to cool from 145° to 70° F.	Relative power of retaining heat.
Lime sand	3 hr. 30 min.	100.0
Quartz sand	3 " 27 "	95.6
Clay loam	2 " 30 "	71.8
Heavy clay	2 " 24 "	68.4
Pure gray clay	2 " 19 "	66.7
Garden soil	2 " 16 "	64.8
Humus	1 " 43 "	49.0
Water	30 " 7 "	860.4

Soil Temperatures for different Depths.

The following table gives the maximum and minimum soil temperatures for various depths, at Urbana, Ill., during the summer of 1904 and the winter of 1904-05, as observed by the Department of Soil Physics Of the University of Illinois.

Depth	Maximum Temperature	Date of Observation	Minimum Temp.	Date of Observ.
Air	92°F.	July 16-18	-24.5°F.	Feb. 13.
1 inch	88	July 18-19	+5.	Feb.2
3 inches	82	July 19	11.	Feb.2
6 "	79	July 17-19	15.	Feb.3
9 "	77	July 18-19	20.	Feb.4
12 "	75	July 19	23	Feb.9
36 "	66	Aug. 17	35	Feb.13-14

Note:- There was about six inches of snow upon the ground Feb.13, 1905, when the air temperature was -24.5, at which time the temperature of the soil at the depth of one inch was +26. There was no snow upon the ground Feb.2d, when the temperature of the soil at the depth of one inch was 5.°0 and the air temperature was -15°F

Thermal Conductivity of Various Materials.

The following values of the thermal conductivity of various materials are given in "Physikalische-Chemische Tabellen" by Landolt and Börnstein, and also in volume II of "Handbuch der Physik" by A. Winkelmann.

Material	Temperature	Thermal Conductivity K	Observer
Aluminum	0	0.3435	Lorenz
Lead	0 to 100	0.0719-0.0836	several
Iron	" " "	0.1417-0.1638	"
Ice		0.00213-0.00568	
Snow, packed		0.000507	Hjelstrom
Glass		0.0013	De la Rive
"		0.00050	Forbes
" ,crown		0.00163	Meyer
" ,flint		0.00143	"
Charcoal		0.000405	Forbes
Coal		0.000297	Neumann
Marble,black		0.00177	Forbes
" , white		0.00115	"

Thermal Conductivity of Various Materials-Continued.

Material	Temperature	Thermal Conductivity	Observer
Flint		0.0024	Hersch, Ledeb, & Dunn.
Limestone		0.0045-0.0049	" " "
", porous, much magnesia		0.0060	" " "
Magn., white, amorph.		0.0044	" " "
Gneiss	0	0.0005779	R. Weber
"	100	0.0004159	"
Slate,	under 0	0.00081	Forbes
Lava	" 0	0.0000833	"
Cement	" 0	0.0001625	"
Chalk		0.0022	Hersch, Ledeb, & Dunn.
Plaster of Paris		0.0013	" " "
Fine quartz sand		0.000131	Forbes
Cork		0.000717	"
Pine, with the grain		0.00030	"
" across " "		0.000088	"
Paraffin		0.000141	"
"		0.0002294	Weber
Horn		0.000087	Forbes
Felt		0.000087	"
Cotton		0.0000433	"
" , pressed		0.0000335	"
Flannel		0.0000355	"
Sack cloth		0.0000298	"
Hair cloth		0.0000402	"
Water		0.001290 to 0.001575	
Copper		0.4152 to 0.7226	

Note:- The above values are for units in the cm.-gr.-sec. system.

Specific Heat of Various Materials.

The following values of the specific heat, in calories per gr., for various materials are taken from "Physikalische-Chemische Tabellen" by Landolt and Bornstein.

Material	Temperature	Specific Heat
Aluminum		0.2088 - 0.2306
Lead		0.02938 - 0.03168
Iron	Ordinary temper.	0.1050 - 0.1151
Copper		0.08988 - 0.09314
Quartz		0.1737
Granite		0.1892 - 0.1940
Gneiss		0.1726 - 0.2143
Sandstone		0.22
Pumice stone		0.24
Lava		0.199 - 0.260
Limestone		0.204 - 0.208
Marble		0.2099 - 0.21585
Air		0.23751 - 0.2389

Surface Radiation and Conduction.

The following constants are taken from a table in Carpenter's Experimental Engineering.

Material	Specific Gravity	Specific Heat	Absorbing and Radiating power. B.T.U. per sq.ft.for 1 dif.of tem.	Conductivity B.T.U. per sq.ft. for 1° dif. of temperature.
Cast iron	7.5	0.1298	0.648	233.0
Wt. iron	7.444	0.1138	0.566	233.0
Steel	7.834	0.1165		
Chalk	2.784	0.2149	0.6786	
Limestone	3.156	0.2174	0.735	
Masonry	2.240	0.2	0.735	
Marble,gray	2.686	0.2694	0.735	28.0
" ,white	2.650	0.2158	0.735	22.4
Oak	0.86	0.57	0.73	1.7
Pine,white	0.55	0.65	0.73	0.748
Charcoal,pine	0.44	0.2415		
Coal,anthracite	1.43	0.2411		
Coke	1.00	0.203		
Glass	2.89	0.1977	0.5948	6.6
Sulphur	2.03	0.2026		
Air at 32 F.	0.00122	0.238		